Center for Water Resources Research Annual Technical Report FY 2010

Introduction

The Utah Center for Water Resources Research (UCWRR) is located at Utah State University (USU), the Land Grant University in Utah, as part of the Utah Water Research Laboratory (UWRL). It is one of 54 state water institutes that were authorized by the Water Resources Research Act of 1964. Its mission is related to stewardship of water quantity and quality through collaboration with government and the private sector.

The UCWRR facilitates water research, outreach, design, and testing elements within a university environment that supports student education and citizen training. The UCWRR actively assists the Utah Department of Environmental Quality (UDEQ), the Utah Department of Natural Resources (UDNR), the State Engineers Office, all 12 local health departments, and several large water management agencies and purveyors in the state with specific water resources problems. In FY 10, the UWRL expended a total of approximately $10 million in water research support. USGS Section 104 funds administered through the UCWRR accounted for less than one percent of this total. These funds were used for research addressing water and wastewater management problems, outreach, information dissemination, strategic planning, water resources, and environmental quality issues in the State of Utah.

One research project was funded in FY10 with funds from a 104-h grant, and two projects were funded from the 104-b program. These projects are respectively entitled, (1) "Drought Index Information System Development for NIDIS", (2) “Analyzing the Spread of *Phragmites australis* over Short Time-scales Using Spatial and Genetic Tools,” (3) “Development of Flood Emergency Response Capability Using UAV’s,” and (4) "Developing a Priority System for Managing Sediment in Smaller Reservoirs." These projects dealt with the following water management issues: (1) development of a capability to evaluate and implement drought indices on a spatial basis for inclusion in a National Integrated Drought Information System (NIDIS) pilot study creating a drought early warning system for the Upper Colorado River Basin; (2) assessment of changes in wetland vegetation over time using high resolution imagery in several spectral bands obtained by application of low-cost unmanned aerial vehicles, as well as genetic sampling to determine the relative contribution of seeds vs. rhizomes in the spread of invasive *Phragmites* patches in a Utah wetland over one year under flooded vs. unflooded conditions; (3) assessment of the use of unmanned aerial vehicles (UAVs) in gathering real-time data during emergency flooding conditions in support of flood emergency management decisions; and (4) development of a system to predict sedimentation in Utah reservoirs based on natural factors and specific reservoir characteristic in order to prioritize Utah reservoirs for sediment management actions aimed at maintaining necessary water supplies for the population. The projects all involved collaboration of local, state, and federal water resources agency personnel.

Research Program Introduction

USGS Section 104 funds were used to establish a data server to support the publication of drought index information for the NIDIS Upper Colorado River Basin (UCRB) pilot drought early warning system which aims to enhance access to drought related data and enable custom drought index calculation. A HydroServer using the CUAHSI HydroServer software stack on virtual servers hosted at the Utah Water Research Laboratory (UWRL) data center has been developed to publish drought index values as well as input data used in drought index calculations, with web services for the data sources necessary for drought index calculation. Procedures to aggregate the input data to the time and space scales chosen for drought index calculation have also been developed, and automated data and metadata harvesters that periodically scan and harvest new data from the input databases have been created to ensure that the data available on the drought server are kept up to date.

The Bear River Migratory Bird Refuge (BRMBR) in northern Utah provides critical habitat to migratory birds, but its habitat value is compromised by an invasive grass species, *Phragmites australis,* that actively displaces native vegetation and alters wetland nutrient cycling. USGS 104b funds were used to assess the ability of unmanned aerial vehicles (UAVs) and pattern recognition algorithms to detect fine-scale changes in the geographic distribution of *Phragmites* and other wetland species cover over the course of a year under different environmental conditions. Inexpensive unmanned aerial vehicles (UAVs) were used to acquire georeferenced multi-spectral imagery (over 10,000 images mosaicked and georectified) of the BRMBR in the summer of 2010. State-of-the-art pattern recognition algorithms were developed and applied to analyze the imagery and determine whether wetlands species cover, including *Phragmites,* can be accurately quantified through this high resolution (appx. 25 cm) remote sensing method. These new technologies make it possible to detect and quantify the rate of spread of *Phragmites* in large wetland areas at very high spatial resolution within the span of a single growing season and with an overall classification accuracy of 95% (as compared to the 85% current industry standard for classification algorithms). Intensive genetic sampling also occurred at the sites monitored by the UAVs to assess the spread of *Phragmites* by seeds vs. rhizomes under flooded and unflooded conditions. The ability to accurately assess changes in wetland vegetation over time will be beneficial for both ecological research and natural resources management.

A third project utilizing USGS Section 104 funds examined the utility of unmanned aerial vehicles (UAVs) in gathering real-time data during emergency flooding conditions in support of flood emergency management decisions. Floods represent a hazard to infrastructure, utilities, and emergency and flood response personnel, and an efficient and comprehensive emergency response saves lives and property. This project studied the potential needs of emergency response teams for a mock flood event in a 100-year floodplain in Cache Valley Utah. A demonstration flight showed the capability of the UAV to produce high resolution photos of bridge crossings, sediment deposits, debris, and river banks. Meetings conducted with emergency response personnel following the demonstration flight discussed the need and ability of the UAV to accomplish many other emergency response objectives such as monitoring and detecting flood damage; aiding in victim and property recovery; and identifying and monitoring potential oil leaks, broken oil and gas lines, downed power lines, and loose propane tanks. The use of UAVs in emergency response and post-flood damage assessment and surveys is a significant benefit for flood emergency response efforts.

Due to the large number of reservoirs in Utah and the necessity of maintaining water supplies for the population, the development of a system to predict sedimentation in reservoirs based on natural factors and specific reservoir characteristics as a way to prioritize reservoirs in Utah for sediment management actions has been proposed. The final project supported with Section 104 funds this year researched and compiled variables for seventeen reservoirs from several different data sets and used that information in a statistical analysis to determine which variables significantly affect the sedimentation of reservoirs in Utah. An equation was developed to predict the sedimentation rate of individual reservoirs, expressed in percent annual capacity loss, which can be used to determine whether the reservoir should be surveyed.

These projects involved collaborative partnerships with various local, state, and federal agencies throughout the state.

USGS Grant No. G10AP00039 Drought Index Information System for NIDIS

Basic Information

Title:	USGS Grant No. G10AP00039 Drought Index Information System for NIDIS
Project Number:	2008UT134S
Start Date:	1/1/2010
End Date:	12/31/2012
Funding Source:	Supplemental
Congressional District:	UT 1
Research Category:	Climate and Hydrologic Processes
Focus Category:	Drought, None, None
Descriptors:	
Principal Investigators:	David Gavin Tarboton, Jeffery S. Horsburgh

Publications

There are no publications.

Drought Index Information System Development for NIDIS

Investigators

David G. Tarboton
Jeffery S. Horsburgh
Graduate Student: Jeanny Miles
Programmer: Stephanie Madsen

Duration

1/1/2010-12/31-2011

Project Description:

The National Integrated Drought Information System (NIDIS) pilot study is focused on the creation of a drought early warning system for the Upper Colorado River Basin. Utah State University has a project that is part of this study for development of a capability for evaluation and implementation of drought indices on a spatial basis. This involves the creation of a geographic database that is linked to historical time-series and real-time hydroclimatic data available over the web. To facilitate this we are establishing a NIDIS drought index server using the capability of and technology from the Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI) Hydrologic Information System (HIS). The CUAHSI HIS is an internet based system that supports the sharing of hydrologic data. It consists of databases connected using the Internet through web services as well as software for data discovery, access and publication. The NIDIS HIS server will support the storage of drought index values and supporting input data, the sharing of this data on the web using WaterOneFlow web services and the WaterML data transmission format. The server will include map presentation services for the display of map based drought index information. The CUAHSI HIS uses a desktop application, HydroDesktop, for client-based data access. This is extendible through plug-in capability. We will develop a drought index plug-in to HydroDesktop that will support access to drought index values and supporting information published on the NIDIS server as well as the capability to compute and display custom drought index products.

Accomplishments (1/1/2010-5/1/2010):

This project started January 1/2010 and is still at an early stage of development. The first year of the project primarily involves system development that comprises (1) setting up a NIDIS HIS server, (2) establishing the system, procedures and agreements for gaining access to and publishing NIDIS drought information, and (3) developing the HydroDesktop plugin to support the calculation and display of custom drought index products.

To date a HIS Server has been established as a virtual machine within the Utah Water Research Laboratory data server cluster. Five sets of web services have been identified as required to support the calculation of drought indices, namely:

- SNOTEL
- StreamFlow
- Soil Moisture
- Precipitation
- Reservoir Levels

We have developed a web service to publish SNOTEL data in the WaterML data transmission format and work is under way for the other data sets.

Work Plan (5/1/2010-12/31/2011):

Following establishing the NIDIS drought HIS Server using CUAHSI HIS functionality, our ongoing work will involve the following:

- Establishing procedures for ingesting data into the Observations Data Model (ODM) relational database used by HIS from its primary source and format, drawing upon ODM loader and potentially SQL Server Integration Services capabilities. Primary data sources may be web or ftp sources, or National Weather Service (NWS) Standard Hydrometeorological Exchange Format (SHEF) data streams. Specifically we anticipate obtaining the NRCS SWSI and supporting information in SHEF format.
- Setting up WaterOneFlow Web services for both calculated drought index values and the data inputs used to generate them.
- Setting up map display and visualization services.

Work will also include development of a HydroDesktop plugin that supports user customizable calculation of drought indices based on data available through the NIDIS drought HIS Server.

The HydroDesktop client and drought index plugin will support the following functionality.

- Access to drought index calculation inputs
- Access to published drought index values
- Ability to flexibly work with drought index relevant information to compute and evaluate different custom drought index products and related measures

In the second year of the project we will conduct training workshops on NIDIS HIS in Utah, Wyoming and Colorado. We also plan to iteratively refine and enhance the NIDIS HIS Server and HydroDesktop plugin based on feedback from users.

USGS Grant No. G10AP00039 Drought Index Information System for NIDIS

Basic Information

Title:	USGS Grant No. G10AP00039 Drought Index Information System for NIDIS
Project Number:	2010UT134S
Start Date:	1/1/2010
End Date:	12/31/2012
Funding Source:	Supplemental
Congressional District:	
Research Category:	Climate and Hydrologic Processes
Focus Category:	Drought, None, None
Descriptors:	
Principal Investigators:	David Gavin Tarboton

Publications

There are no publications.

Progress Report: USGS Grant No. G10AP00039 Drought Index Information System for NIDIS

David Tarboton

May, 2011

Current Status

Utah State University has established a data server to support the publication of drought index information for the NIDIS Upper Colorado River Basin (UCRB) pilot drought early warning system. The goals are to enhance access to drought related data and enable custom drought index calculation. The approach has been to first establish a foundation of primary hydrologic information related to drought in the UCRB pilot available through the Consortium of Universities for the Advancement of Hydrologic Science Inc. (CUAHSI) Hydrologic Information System (HIS), then aggregate this data at time and space scales most relevant for drought index calculation and publish it using HIS so that local customized drought index evaluation is enabled.

The CUAHSI HIS is a federated system for sharing hydrologic data. It is comprised of multiple data servers, referred to as HydroServers, that publish data in a standard XML format called Water Markup Language (WaterML), using web services referred to as WaterOneFlow web services. HydroServers can also publish geospatial data using Open Geospatial Consortium (OGC) web map, feature and coverage services and have a web interface for data access. HydroServers use a Microsoft Windows Server operating system and ESRI ArcGIS Server platform to publish data from Microsoft SQL databases and ArcGIS server files. Time series data is stored in SQL Server databases using the Observations Data Model (ODM). HIS also includes a centralized metadata catalog that indexes data from registered HydroServers and a data access client referred to as HydroDesktop.

For the NIDIS project, we have already built a HydroServer using the CUAHSI HydroServer software stack on virtual servers hosted at the Utah Water Research Laboratory (UWRL) data center. The drought HydroServer was developed as a platform to publish drought index values as well as the input data used in drought index calculations. Primary input data required for drought index calculation include streamflow, precipitation, reservoir storages, snow water equivalent, and soil moisture. Before this project began, only streamflow from the USGS National Water Information System (NWIS) was available as a standard WaterOneFlow web service. In year one of this project, we worked to establish web services for other data sources necessary for drought index calculation, including USBR reservoir storage values and NCDC precipitation data. These efforts were necessary to ensure that the inputs to drought index calculations are available via consistent web services and delivered in a consistent format (i.e., WaterML). We also developed procedures to aggregate the input data to the time and space scales chosen for drought index calculation, i.e. half monthly time intervals for HUC 10 subwatersheds. We have created automated data and metadata harvesters that periodically scan and harvest new data from each of the input databases, ensuring that the data available on the drought server is kept up to date. These harvesters also aggregate the data in time and space to half monthly and HUC 10 subwatershed scale.

The USU NIDIS HydroServer currently hosts the following WaterOneFlow web services:

- SNOTEL (http://drought.usu.edu/SNOTEL/cuahsi_1_1.asmx?WSDL). This is a flow through data service to provide access to data for the six standard variables available at all SNOTEL sites. Metadata describing the sites and variables is stored on the drought server, but data requests retrieve the latest data directly from the NRCS. Current data is retrieved from NRCS data published in directories under http://www.wcc.nrcs.usda.gov/ftpref/data/snow/snotel/cards/, with sites from http://www.wcc.nrcs.usda.gov/nwcc/sitelist.jsp.
- NCDC Precipitation, http://drought.usu.edu/NCDC_Precip/cuahsi_1_1.asmx?WSDL. This is a hold and serve data service to provide access to NCDC precipitation data within a 50 mile buffer around the Upper Colorado River basin watershed. NCDC has established a REST web service described at http://www7.ncdc.noaa.gov/wsregistration/ws_home.html for access to its climate data (including precipitation). NCDC also publishes its data on an ftp site: ftp://ftp3.ncdc.noaa.gov/pub/data/3200/. Our efforts to use the REST web service for full length of record data retrievals found this service to be unreliably slow, so our strategy in establishing access to precipitation data has been to download from the ftp site the entire period of record of data for the Upper Colorado River basin, parse and load this into an ODM database, and publish WaterOneFlow services from this ODM database. We have also designed a data harvester that uses periodic calls to the REST web service to load the most recent data into the ODM database hosted at USU so that the precipitation data available from this service is always up to date. The web service publishing the historic data is in place and loading of the historic data is complete. The programming for the data harvester is in progress and should be complete by the end of April 2011.
- USBR Reservoir Data, http://drought.usu.edu/USBRReservoirs/cuahsi_1_1.asmx?WSDL. This is a flow through data service to provide access to data from US Bureau of Reclamation reservoirs. Metadata is stored on the drought server, but data requests retrieve the latest data from the USBR website http://www.usbr.gov/uc/crsp/GetSiteInfo.
- SNODAS. Three SNODAS web services have been established to publish data from the NOHRSC snow data assimilation system. These are at different levels of spatial aggregation: HUC12, http://drought.usu.edu/SNODAS_HUC12/cuahsi_1_1.asmx?WSDL; HUC10, http://drought.usu.edu/SNODAS_HUC10/cuahsi_1_1.asmx?WSDL; HUC8, http://drought.usu.edu/SNODAS_HUC8/cuahsi_1_1.asmx?WSDL. Currently these hold model simulation results of snow water equivalent provided by NOHRSC. Procedures are not in place yet for periodic updating of this data as new SNODAS product results become available.

The primary streamflow data source is the USGS NWIS daily streamflow service established by CUAHSI in partnership with the USGS (http://river.sdsc.edu/WaterOneFlow/NWIS/DailyValues.asmx). We have established a list of gauging stations within the pilot area based on length of record and developed a harvester to ingest this information into the NIDIS drought server on a regular basis.

The above primary data sources are ingested and aggregated in time and space into an ODM database that we call the NIDIS summary database that is used to publish processed and aggregated (value added) drought information for the UCRB pilot area. The summary time series web service is at: http://drought.usu.edu/NIDISTimeSeries/cuahsi_1_1.asmx?WSDL.

In addition to the above observational data web services, we have also published the following GIS datasets as OGC map services on the NIDIS HydroServer.

- UCRB Study Area
- NIDIS Monitoring Sites
- USGS HUCS
- UCRB Major Rivers
- ESRI Street Base Map

These underlie the HydroServer map application (http://drought.usu.edu/nidismap/) that provides map based display of drought information over the UCRB pilot.

We have organized the preparation of data for use in drought index evaluation into the following levels:

Level 1. This is the original time series data observed at points as obtained from the data source.

Level 2. This is data that has gone through one degree of aggregation. Level 2A refers to data that has been aggregated in time from its initial time step (usually daily) to the time step chosen for drought analysis (half monthly). The method of aggregation depends on the quantity being aggregated. For example, precipitation is totaled, streamflow is averaged and converted to a volume (acre-ft) quantity, and reservoir storages at the end of the interval are recorded. Level 2B refers to data that has been aggregated in space (but not in time) from its initial data source. The ultimate goal is to have data aggregated in both space and time, but sometimes the time aggregation is done first (Level 2A) while other times the space aggregation is done first (Level 2B).

Level 3. This is data that has been aggregated in both space and time and is thus available at half monthly time step at the HUC 10 spatial scale.

Level 4. This is the statistical transformation of the level 3 data into a drought index, or drought index information, such as representing the quantity involved (e.g. reservoir storage within a HUC 10 watershed at the end of an interval) as a percentile of the historical reservoir storage.

The following table summarizes the status of each of the levels of data in the NIDIS HydroServer.

	Streamflow	Precipitation	Reservoir Storage	SNOTEL	SNODAS
Primary data source	USGS NWIS	NCDC FTP site and REST Service	USBR Website	NRCS Website	NOHRSC
Level 1	CUAHSI Daily Streamflow WaterOneFlow service	USU NCDC precipitation WaterOneFlow service in progress	USU USBR Reservoir storage WaterOneFlow service	USU SNOTEL WaterOneFlow service	There is no level 1 SNODAS data. We receive SNODAS data aggregated to HUC 8, 10 and 12 watershed scale
Level 2	Aggregated to level 2A	In progress	Aggregated in time to level 2A.	Aggregated in time to level 2A	USU SNODAS WaterOneFlow services for HUC 8,10 and 12
Level 3	Evaluation of weights for aggregation to level 3 in progress	In progress	Aggregation for HUC watersheds underway	Not planned	Aggregate in time still to do
Level 4	Still to do	Still to do	Still to do	Still to do. Indices to be based on point SNOTEL SWE	Aggregate in time still to do
Color Code	Done	In Progress	Still to do		

Future Work

This is a multi year project and we have submitted a proposal that is currently being evaluated by the USGS for ongoing work. Following are goals for year two and tasks that will be completed if the second year proposal is funded.

1. Complete development of the prototype capability to provide through CUAHSI WaterOneFlow web services the comprehensive data required for the evaluation of drought indices.
2. Publish through CUAHSI WaterOneFlow web services key drought indices based on the comprehensive supporting data.

3. Enhance capability for visualization of drought index and supporting data.
4. Develop capability that enables users to define and evaluate their own custom drought indices.

These goals have been framed recognizing that the primary purpose of the HydroServer already developed is to publish data using WaterOneFlow web services. Although HydroServer does provide some visualization functionality through its ArcGIS map server based map display and time series analyst graphing functionality, our discussions with the NIDIS portal development team have lead us to the conclusion that the emerging capability of the NIDIS map client is a better place to develop map display capability than HydroServer. Our project best complements the NIDIS portal development through the delivery of data services that can be consumed at the NIDIS portal and displayed through the web client under development there. We can also contribute by assisting to define user functionality requirements for display of hydrologic/drought information in the web map client. The already developed HydroServer is a prototype on a relatively limited hardware platform that can only serve modestly light data delivery demands suitable for prototype development. The extent of these limitations has not been established. If loads on this system become heavy, plans for scaling up the server capability will need to be made and are beyond our current scope.

Tasks

Specific tasks proposed for year two, to meet the above goals are:

1. Complete the development of streamflow, Precipitation, Reservoir Storage and SNOTEL and SNODAS data published through the drought HydroServer to level 4 and publish drought indices based on this information.
2. Work with National Weather Service Colorado Basin River Forecast Center to develop access to additional data from their holdings through the NIDIS HydroServer including streamflow forecasts and SWSI values they develop in conjunction with the NRCS.
3. Work with the NIDIS portal development team in support of their development of methods for consuming WaterOneFlow web services by the NIDIS map client for display at the NIDIS portal
4. Development of functionality for HydroDesktop that enables the calculation of custom, user defined drought indices based on WaterOneFlow web services published by the NIDIS HydroServer. In developing this functionality we will iterate with early implementers and friendly evaluators to identify requirements for this customization of HydroDesktop that supports their needs.

Analyzing the Spread of Phragmites Australis Over Short-Time Scales Using Spatial and Genetic Tools

Basic Information

Title:	Analyzing the Spread of Phragmites Australis Over Short-Time Scales Using Spatial and Genetic Tools
Project Number:	2010UT137B
Start Date:	3/1/2010
End Date:	2/28/2011
Funding Source:	104B
Congressional District:	UT1
Research Category:	Ground-water Flow and Transport
Focus Category:	Surface Water, Invasive Species, Wetlands
Descriptors:	None
Principal Investigators:	Karin Kettenring, Shannon Clemens, Austin Jensen, David Rosenberg

Publications

There are no publications.

Analyzing the Spread of *Phragmites australis* Over Short Time-Scales Using Spatial and Genetic Tools

Problem Description

Accurately assessing changes in wetland vegetation over time is important for both ecological research and natural resource management. A fundamental question in ecology is what drives the distribution of plant species; addressing this question implies that we are able to accurately determine where certain species occur and how their occurrence changes over time. At the same time, natural resource managers need to be able to determine where desirable native plant species occur and how management activities drive changes in vegetation. One of the biggest challenges for natural resource managers is whether they can accurately track changes in invasive plant species, either their expansion or their retraction, in response to control efforts. Many currently available remote sensing strategies do not operate at a fine enough resolution to be useful for these ecological and management purposes. For example, satellite imagery lacks sufficient spatial resolution to provide decision-relevant information to wetlands managers. Imagery obtained from the use of conventional aircraft platforms is too expensive for many wetlands management applications. In contrast, high-resolution imagery can be obtained from the application of unmanned aerial vehicles (UAVs) at very low cost in several different spectral bands. This technology will be explored in this project.

One of the most problematic invasive species in wetlands in North America is *Phragmites australis* (Galatowitsch et al. 1999). This aggressive grass species, introduced from Europe more than one hundred years ago, actively displaces native vegetation (Marks et al. 1994). The consequences of *Phragmites* invasion include a loss of flora and fauna and alternations to wetland nutrient cycling (Marks et al. 1994; Meyerson et al. 1999; Meyerson et al. 2000; Windham and Ehrenfeld 2003). In northern Utah, *Phragmites* is invading many of the brackish wetlands of the Great Salt Lake (Kettenring, pers. obs.). These wetlands provide critical habitat to migratory birds on the Pacific flyway, but their habitat value is compromised by *Phragmites* invasion. Managers need tools to document the occurrence and expansion of *Phragmites* in order to know where to target control efforts and to know what native plants are being replaced by *Phragmites*. Similarly, to assess the success of control efforts, rates of retraction are also needed. New technologies developed by the Utah Water Research Laboratory for acquiring remotely sensed data and for quantifying the distribution of vegetative types over a large area may provide important tools for estimating the spread of invasive species, but they have not been previously evaluated in a wetland setting.

Thus, this research will address the following question: **Are UAVs and pattern detection algorithms able to detect fine-scale changes in *Phragmites* and other wetlands species over the course of a year? Can this technology be used to calculate rates of *Phragmites* expansion over one year under varying environmental conditions? Similarly, can this technology be used to determine what native plant species *Phragmites* is replacing as it invades?**

Phragmites can spread by both seeds and rhizomes (underground stems). However, the contribution of seeds versus rhizomes to *Phragmites* spread is just beginning to be understood (Bart and Hartman 2002, 2003; League et al. 2006; McCormick et al. 2010). One important piece of information that has not been assessed is how much spread within existing stands of *Phragmites* is by seed versus rhizomes. To complement efforts to assess fine-scale changes in *Phragmites* cover, genetic techniques will be used to determine the relative contribution of seeds versus rhizomes in *Phragmites* spread. To address this research need, we ask the following question: **What is the relative importance of spread by seed versus rhizomes in the expansion of *Phragmites* patches over the course of one year?**

Study Area

The research was conducted at the Bear River Migratory Bird Refuge (BRMBR) which is located on the northeast shore of the Great Salt Lake, Utah, at the terminus of the Bear River. The Refuge is managed by the U.S. Fish and Wildlife Service as part of the National Wildlife Refuge System; comprises over 115 square miles of marsh, open water, uplands, and alkali mudflats; and is one of the largest wetland complexes along the Great Salt Lake. With this location and size, the Refuge provides critical wetlands wildlife habitat and resting grounds for migratory birds along the Pacific Flyway. It is one of the most important habitat areas for migratory birds in North America.

BRMBR managers use an engineered system of dikes, canals, radial gates, weirs, and other water control structures to regulate water flows into and out of 23 wetland units in the marsh and open water areas. Together, these units cover an area of approximately 43 square miles and comprise and allow for a diverse mix of wetland habitats such as open water, native vegetation, invasive vegetation, and mixtures of native and invasive vegetation within a very small geographic area. BRMBR managers are very concerned about the spread of invasive vegetation such as *Phragmites* within Refuge wetland units. They would like to quantify the current extent of the *Phragmites* invasion plus better understand how *Phragmites* is invading over time. Managers are also very interested to deploy cheap yet effective technology that can better help them monitor and quantify the response of *Phragmites* and other species, both invasive and native, to their ongoing vegetation management activities.

Scope of Work

The following project objectives were identified to address our research questions:

1. To assess the ability of unmanned aerial vehicles (UAVs) and pattern recognition algorithms to detect fine-scale changes in the geographic distribution of *Phragmites* and other wetlands species cover over the course of a year.

2. To determine rates of expansion of *Phragmites* over one year under different environmental conditions.

3. To determine the relative importance of spread by seed versus spread by rhizomes in the expansion of *Phragmites* patches over one year under different environmental conditions.

The following work was conducted to achieve these objectives:

Work Plan, Objective 1: Inexpensive unmanned aerial vehicles (UAVs) were used to acquire georeferenced multi-spectral imagery of the BRMBR. The imagery was then analyzed by state-of-the-art pattern recognition algorithms to determine whether wetlands species cover, including *Phragmites*, can be accurately quantified through these high-resolution remote sensing methods.

The Utah Water Research Laboratory (UWRL) and the Center for Self-Organizing Intelligent Systems (CSOIS) at Utah State University (USU) have developed UAVs for use in water-related research activities. The UAV platform, named "AggieAir™", has the capability of carrying multiple cameras that capture imagery in the visual and near-infrared bands at a spatial resolution of 5 to 25 cm, depending on the altitude of flight. For more information on AggieAir, refer to http://aggieair.usu.edu/.

Aerial imagery in the red, green, blue, and near-infrared spectra were obtained for approximately 50 square miles of the BRMBR. This was used to produce a high-resolution base map of the entire area wherein *Phragmites* is known to be a problem. In combination with on-ground field inspections, the base map was used to identify specific areas or patches, totaling approximately 12 square miles, where UAVs would conduct aerial sampling at three later points in time. These were used in order to acquire imagery needed to measure the spread of *Phragmites* throughout the period of a year. Each of these four high-elevation UAV flights (i.e., one 50 square mile flight and three later flights of about 12 square miles, each) yielded mosaiced and georectified images that have a resolution of approximately 25 cm.

Before the 25-cm resolution images could be used to recognize areas where *Phragmites* and other species are growing, it was necessary to intensively sample approximately 100 very small sites, each of only a few square meters, to establish the base data for use in training the pattern recognition algorithms to detect *Phragmites* and other wetlands species. These sites were sampled using on-ground field observations and highly accurate GPS equipment. The data obtained was used to train and test a learning machine for classification of wetlands cover using the spectral data from the 25-cm resolution images.

Recognition of wetland vegetation using remote sensing is very difficult (Yamagata and Yasouko, 1993). A machine learning strategy which uses remotely sensed reflectance data to classify the wetland vegetation into different categories was developed for use in this project. The approach is based on a multiclass relevance vector machine (MCRVM) that has recently produced excellent results for multiclass landcover classification and crop identification (Zaman and McKee, under review). The machine has been shown to have good generalization capability and proved to be extendable to wetlands species classification. A MCRVM model was trained with the remotely sensed vegetation reflectance data and the data obtained from the on-ground sampling. After the MCRVM model was trained, it was used to classify previously unseen data into different categories, including various vegetation types, especially *Phragmites*.

Work Plan, Objective 2: Aerial imagery was obtained at four different times during the year. For each of these flights, imagery was captured for approximately 12 square miles of the

BRMBR in both the RGM and NIR bands. Over the entire season, this produced approximately 10,000 images that were mosaicked and georectified using the EnsoMOSAIC software package that is designed for this purpose. These georectified images were analyzed using the MCRVM classification technology previously described, which yielded estimates of the distribution of *Phragmites* and other wetlands species over large areas of the BRMBR at different points in time that correspond with the dates of the UAV flights. These data were then analyzed with change-detection algorithms to describe the expansion of *Phragmites* over large areas that are growing under different environmental conditions (e.g., flooded, saturated, or dry soils).

Work Plan, Objective 3: We identified 20 *Phragmites* patches (which were being monitored by the UAV flights) to sample intensively for assessment of spread by seeds versus rhizomes. We targeted 10 patches in flooded wetland areas and 10 patches in unflooded areas to test our hypothesis that *Phragmites* spreads predominantly by rhizome under flooded conditions but by seeds under unflooded conditions. Our sampling scheme for each patch is shown in Figure 1. Our approach was to collect leaves every 0.5 m along each of two 25m transects. The first transect, innermost to the patch, followed the edge of the densest part of the patch. The second transect followed the edge of the patch at 25-50% of maximum stem density. We also sampled any "stragglers" that were on the invasion front of the patch that were at <10% of maximum stem density. The very dense sampling scheme used in this initial phase of the project was intended to allow us to optimize our sampling strategy in future efforts to maximize the number of patches tested without losing significant information on genetic richness.

Leaf samples collected in the field were preserved by placing in paper envelopes submerged in a silica gel desiccant and transported to the laboratory. In the laboratory, DNA was extracted from the leaf tissues using a Qiagen DNEasy 96 Plant Kit. Variation in individual DNA samples was characterized using a molecular marker system known as "amplified fragment length polymorphism" analysis, or AFLPs. This technique uses a combination of restriction enzymes and polymerase chain reaction (PCR) to identify mutation sites differing among DNA samples, and allows the identification of genetically unique individuals. Using this technique we analyzed data from 110 variable sites (loci) in the *Phragmites* genome. This set of loci gave us ample statistical power to discern genetically distinct individuals (genets) that arose from different seeds, and also allowed us to identify multiple stems (ramets) that arose originally from the same seed but which have spread vegetatively through rhizomes. Thus, we were able to determine relative spread by seed versus rhizome in each patch under flooded versus unflooded conditions. Initially, we analyzed the leaf samples from just four of the twenty patches to determine the optimal number of samples per patch to analyze.

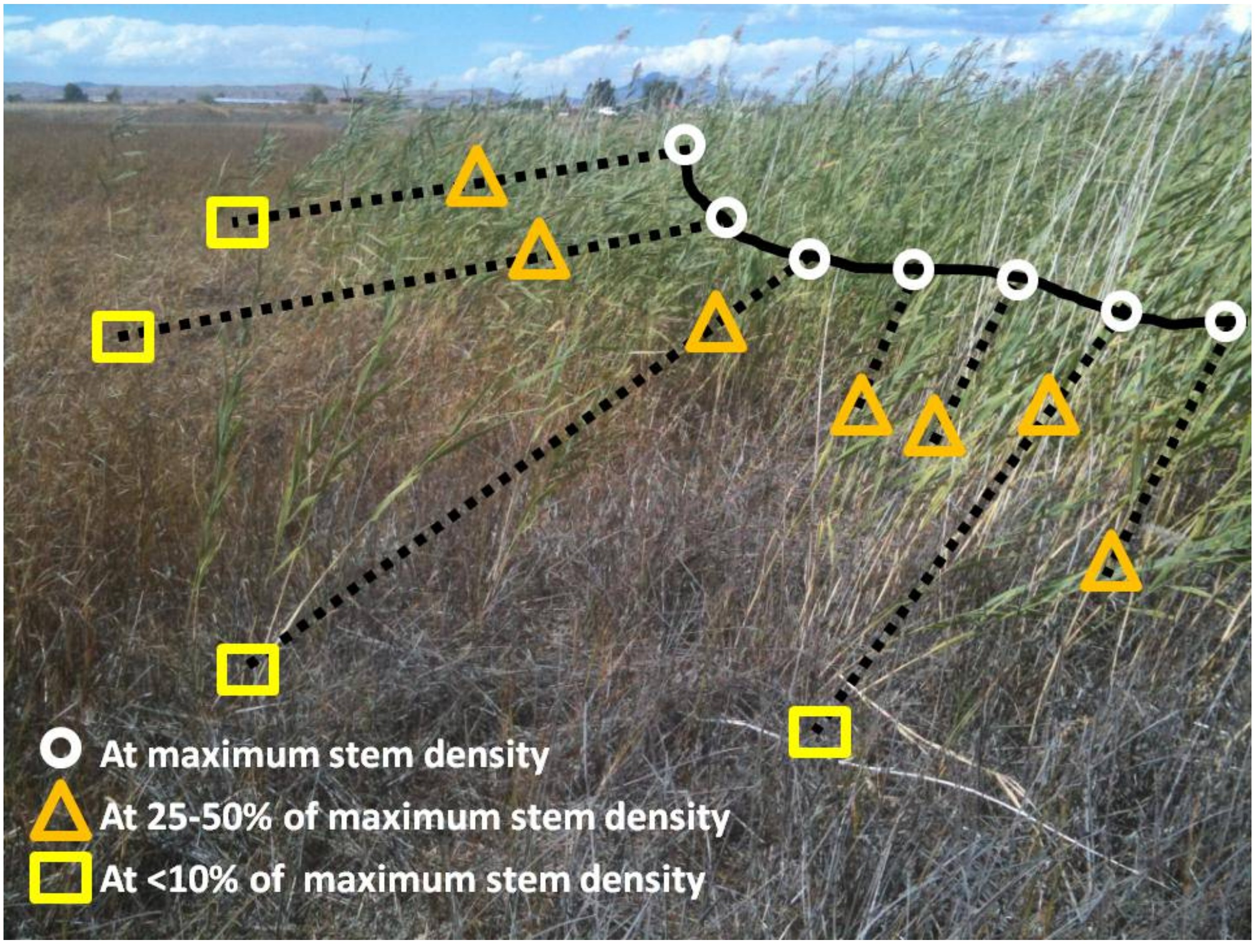


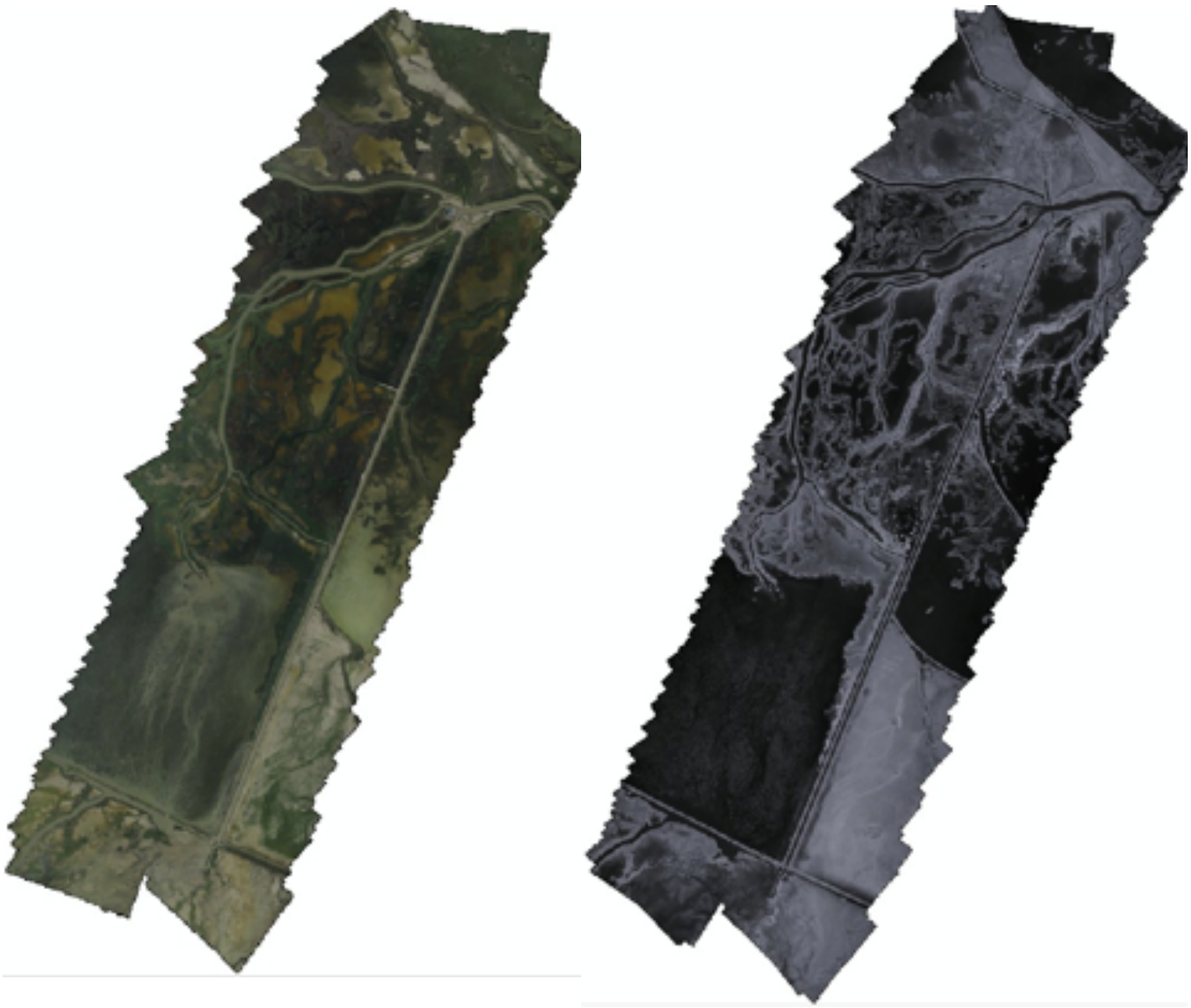
Figure 1. Sampling scheme for *Phragmites* leaf collection for genet diversity assessment.

Results

Aerial Tracking of *Phragmites*

Four different UAV flights were conducted with the AggieAir platform in the summer of 2010 to test the capability of the aircraft in acquiring imagery that can be used to automatically identify *Phragmites*. These yielded imagery in the visual spectrum (i.e., red, green, and blue, or "RGB") and in the near infrared spectrum (NIR). Examples of the imagery obtained in these spectra are shown in Figure 2.

Classification of area covered by *Phragmites* was accomplished through the development and application of a multi-class relevance vector machine (MCRVM) following a supervised classification approach. To do this, the imagery obtained from the AggieAir flights was first processed to transform the digital numbers in the images into normalized reflectance values using the data from a standard reflectance panel ($BaSO_4$). The readings over the $BaSO_4$ panel were obtained using the UAV cameras before and after each image acquisition flight. The MCRVM was trained using these normalized reflectance measurements for the ground sampling points or classes (*Phragmites*, water, salt, other vegetation, etc.) in the red, green, and near-infrared bands. Each class had a unique spectral signature which the MCRVM model used to detect *Phragmites*. Development (or "training") of the MCRVM classification model produced excellent classification results when the model was presented with previously unseen data. The average user's and producer's accuracy for the vegetation data was 95%. Out of 60 test points, only three were misclassified, and for these the posterior probabilities of class membership were close. The overall classification accuracy was 95% (see Table 1). In comparison, application of the conventionally available classification algorithms in the ERDAS Imagine software on the same data, the current industry standard, showed at best a classification accuracy of 85%.



(a) (b)

Figure 2: Example Imagery Acquired from One UAV Flight (four square miles of the Bear River Migratory Bird Refuge, flown on June 17, 2010): (a) Visual Spectrum Imagery (RGB); (b) Near-Infrared Imagery (in false grey-scale)

After the MCRVM was trained, it was used to classify all pixels in the imagery obtained from each of the four AggieAir flights conducted over the 12-square-mile case study area during the growing season of 2010. Examples of the classification results for identification of *Phragmites* are illustrated in Figure 3 (wherein *Phragmites* is shown in black).

Table 1: Results of MCRVM Classification Testing Using Previously Unseen Data

		Classification data						
		Water	Phragmites	Salt/ Concrete	Marsh	Mixed Vegetation	Row Total	PA (%)
Reference Data	Water	9	0	0	0	0	9	100%
	Phragmites	0	19	0	1	0	20	95%
	Salt/ Concrete	0	0	10	0	0	10	100%
	Marsh	1	0	0	9	0	10	90%
	Mixed Vegetation	0	1	0	0	10	11	91%
	Column Total	10	20	10	10	10	60	95%
	UA (%)	90%	95%	100%	90%	100%	95%	95%

Detection of the spread of *Phragmites* during the growing season was accomplished by comparing the results of the MCRVM classification of late-season images against that of early-season images. For example, Figure 4 illustrates the spread of *Phragmites* from June to September, 2010, in a four-square-mile area of the BRMBR. The area shown in green in Figures 4 and 5 represent those locations where the change detection algorithms found at least a 10% change in *Phragmites* during this three-month period. All of the change in *Phragmites* area shown in Figures 4 and 5 is the result of an expansion of the territory occupied by *Phragmites*. The images obtained by use of the UAV technology allow us to achieve these results at a resolution of approximately 25 cm. In total, these data and analyses were accomplished over a total area of approximately 12 square miles.

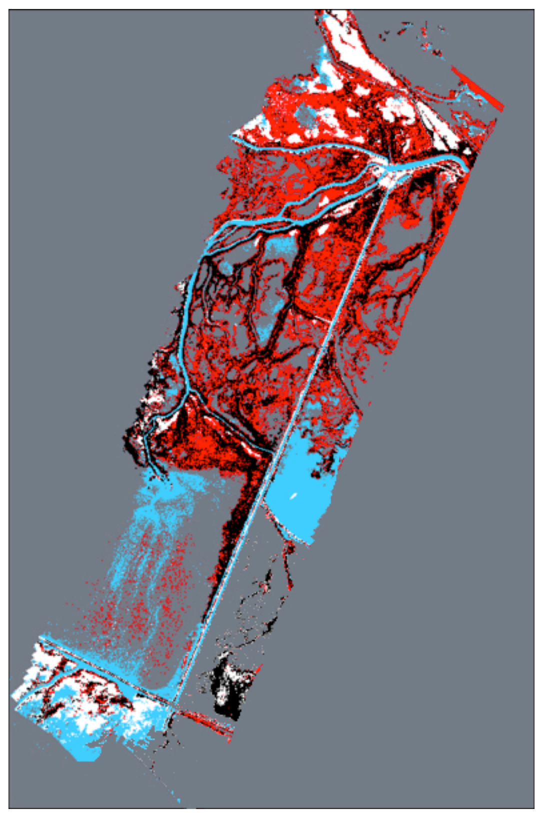


Figure 3: Application of the MCRVM for Classification of Wetlands Cover (*Phragmites* shown in black; total image area is approximately four square miles)

<u>DNA Sampling and Analysis</u>

Overall, out of the 470 samples analyzed, we detected 17 unique genets in the four plots, combined (Table 2). While three of the plots were genetically quite uniform, one of the plots (3D) had remarkably high genetic diversity (genet richness) (Figure 6). Most of the unique genets in Plot 3D were clones of small spatial extent, and these unique genets were clustered together spatially, suggesting an episode of seed establishment. Additionally, it was evident that genets within patches were generally cohesive, and not scattered throughout the patch. We did not detect any differences in *Phragmites* spread between flooded and unflooded patches, although we analyzed only a limited number of patches in this initial effort.

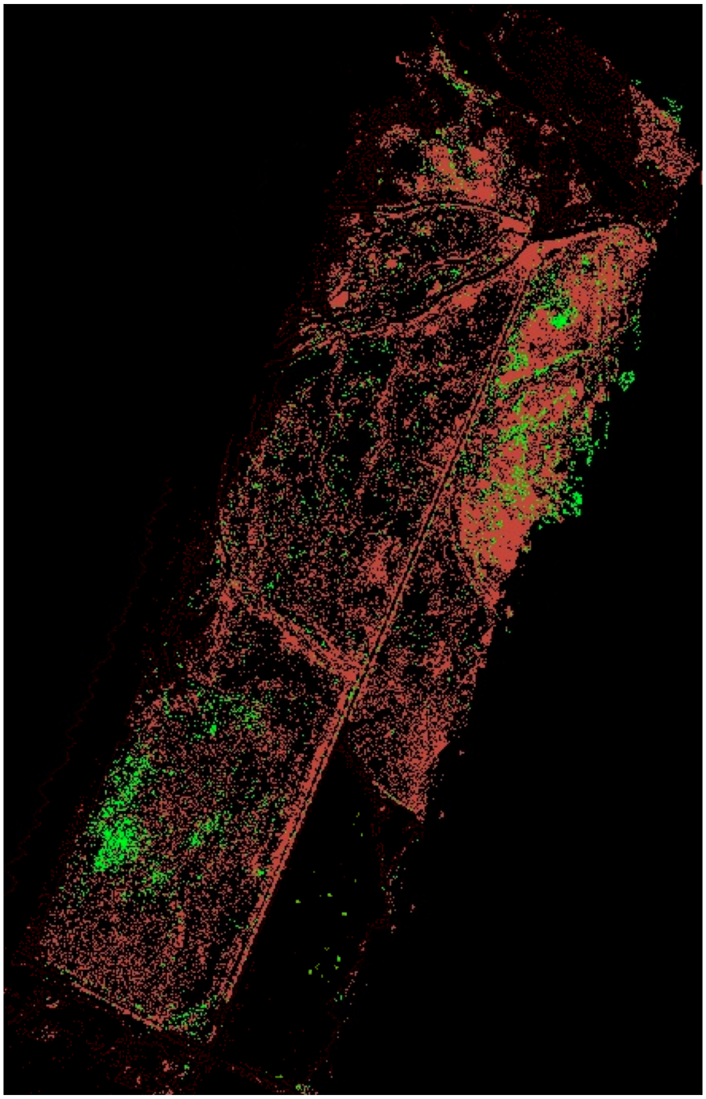


Figure 4: Detection of Expansion of Additional Area Occupied by *Phragmites* in the BRMBR between June and September, 2010 (shown in green, in an approximately four-square-mile area)

The intense sampling strategy revealed that the samples from the two 25m transects provide almost identical genet information. Based on our findings, in future work we will employ a less dense sampling scheme and will only use a single transect along the patch edge (e.g., only sample every 1.5m, rather than every 0.5m, along the length of the transect) along with a sampling of the "stragglers" at the outermost boundary of the patch. This will allow us to extend our sampling to many more patches, and will allow us greater ability to make inferences about flooded versus unflooded areas.

Table 2: Summary of Genet Data

Plot	Treatment	# Samples	# Genets	Genet Richness
3A	flooded	119	1	0.008403
2D	flooded	119	5	0.042017
3D	unflooded	121	10	0.082645
3C	unflooded	112	1	.008929

Conclusions and Recommendations

Acquisition of high-resolution aerial imagery from deployment of UAVs, coupled with post-flight processing for georectification and reflectance normalization, can provide valuable data for assessing the location and rate of expansion of the invasive wetland species, *Phragmites australis*. The Bayesian-based MCRVM classification algorithm was successful in identifying the location of *Phragmites* at high resolution and proved to have superior performance when compared to conventional classification methods. Further, use of the UAV and advanced

MCRVM classification technologies make it possible to detect and quantify the rate of spread of *Phragmites* in large wetland areas at very high spatial resolution and within the span of a single growing season. The DNA sampling work did not detect any correlation between the method of spread of *Phragmites* and whether an area was flooded or dry. This result is based on a limited number of observations, however, and requires further analysis.

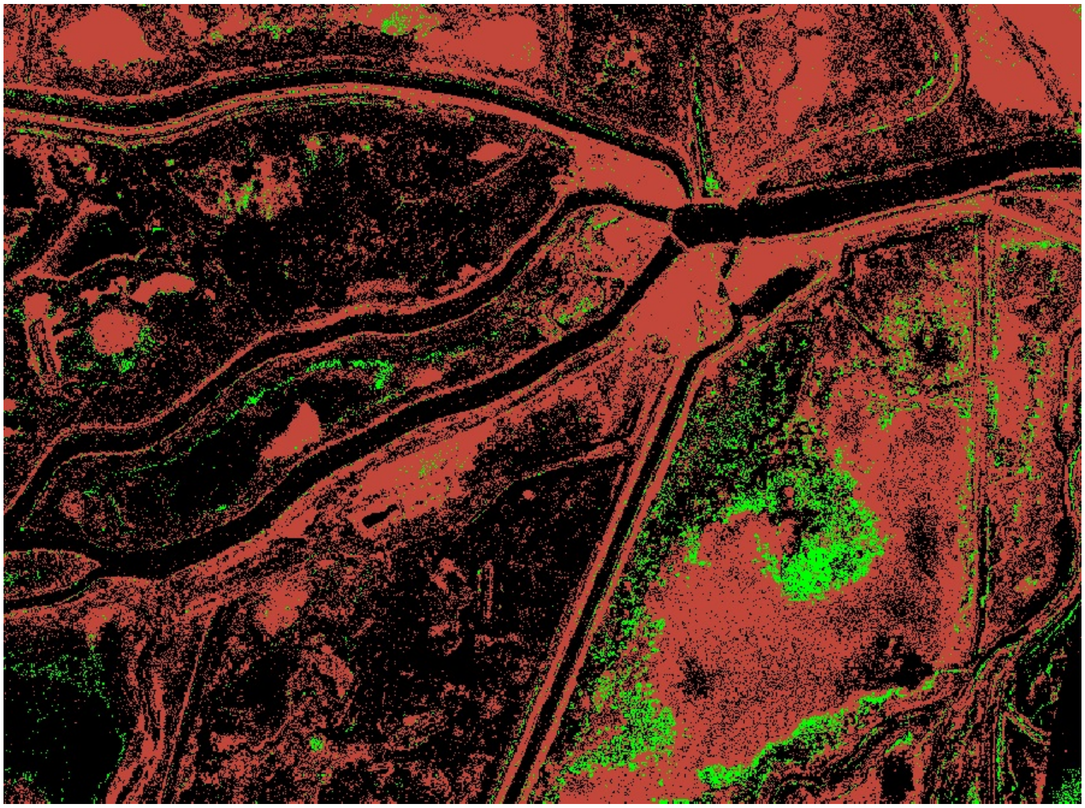


Figure 5: Expansion of Area Occupied by *Phragmites* in the BRMBR (shown in green; enlarged from the upper portion of Figure 4)

DNA sampling and analysis has shown that it is possible to detect different mechanisms of *Phragmites* spread (rhizomes versus seeds) under flooded versus unflooded conditions.

Future work should focus on:

- assessing which species are being displaced by the expansion of *Phragmites* and whether some native species are more or less susceptible to this displacement, and under what conditions,
- determining whether a correlation can be found between the differences in the DNA data and the spectral signals detected in the imagery delivered by the UAVs,
- evaluating the relationship between the success of the strategies of *Phragmites* expansion (seeds versus rhizomes) and the impact of flooding or drying of wetland areas in controlling or limiting such expansion.

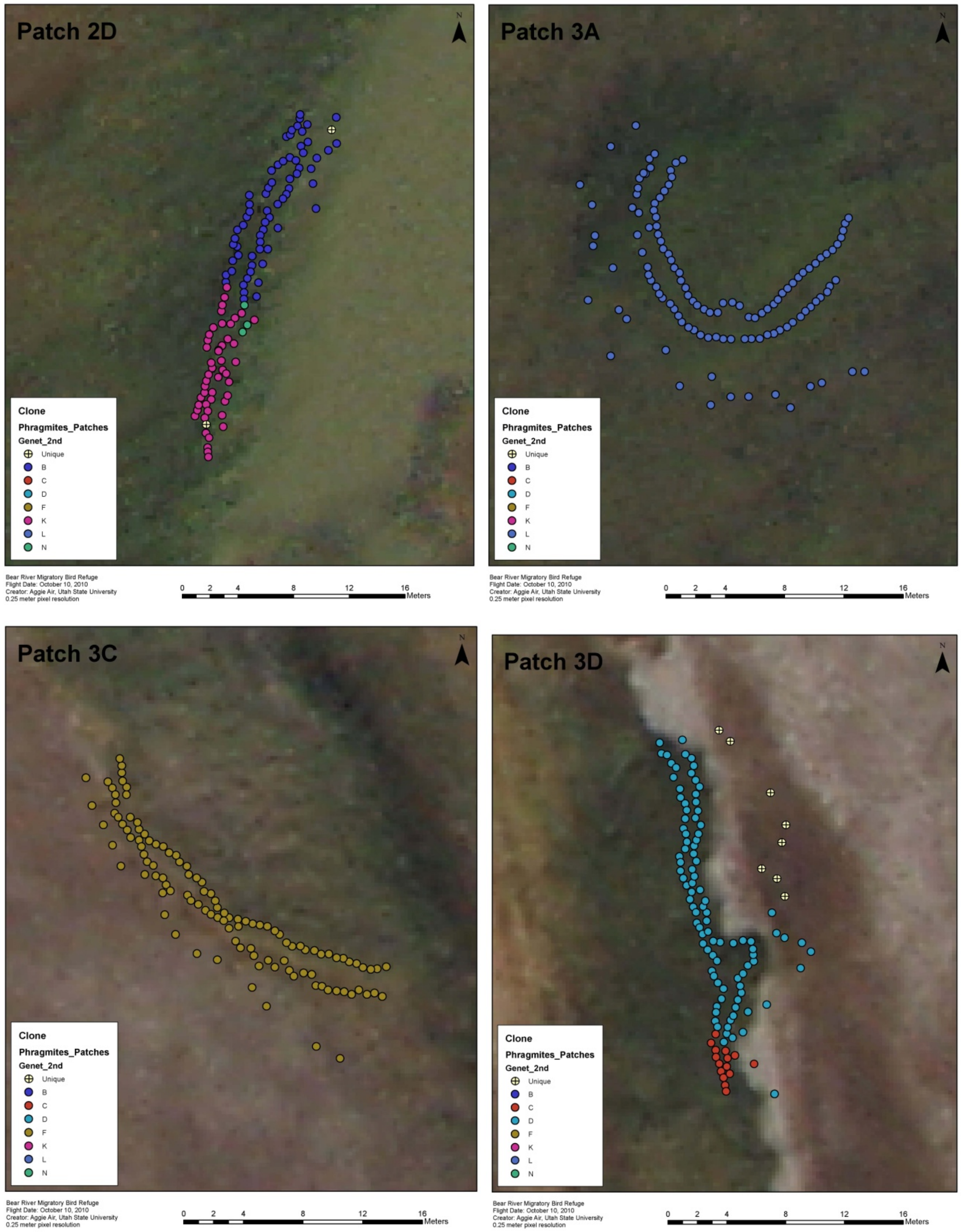


Figure 6: Distribution of different clones within four *Phragmites* patches (flooded patches = 2D, 3A; unflooded patches = 3C, 3D) at Bear River Migratory Bird Refuge. Samples that were genetically identical share a common color. Samples that were genetically unique are denoted with an "x" in a circle (2 samples in 2D, 8 samples in 3D). There were no common clones among patches.

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Development of Flood Emergency Response Capability Using UAV's

Basic Information

Title:	Development of Flood Emergency Response Capability Using UAV's
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Principal Investigators:	William J. Rahmeyer, Shannon Clemens, Austin Jensen

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There are no publications.

DEVELOPEMENT OF FLOOD EMERGENCY RESPONSE CAPABILITY USING UAVs

William Rahmeyer
May 29, 2011

Background

The agencies and personnel who respond to emergency flood events must often contend with significant uncertainties regarding the nature and scope of threats to public safety. Planning and coordinating a real-time response to threatening conditions must often be done with limited knowledge about the details of the extent and location of flooding, the location of people who might be at risk, specific hazards that might have been created by the flood, etc. Further, physical access to flooded areas will frequently be impeded, making it difficult or impossible to acquire data on the state of the flooded system and on the public safety threats that have been created. The purpose of this project is to explore the potential utility of using unmanned aerial vehicles (UAVs) to gather real-time data during emergency flooding conditions in support of flood emergency management decisions.

To understand the benefits and use of a UAV in responding to a man-made or natural disaster, this project studied the potential needs of emergency response for a mock flood event in a 100-year floodplain in Cache Valley Utah. While a flood of this type is typically not categorized as a catastrophe, it still involves the loss of property and the potential loss of life. An efficient and comprehensive emergency response saves lives and property. Any type of flood always represents a hazard to infrastructure, utilities, and emergency and flood response personnel. The information gained from this study has direct implications toward the public safety response to many other types of events such as landslides, dam and canal failures, earthquakes, fires, search and rescue, and any type of attack on property and communities.

Data acquired by aircraft, satellites, and other sources of remote sensing have become very important for many applications of emergency response. Even though current platforms for remote sensing have proved to be robust, they can also be expensive, have low spatial and temporal resolution, and require a long turnover time. A team at the Utah Water Research Laboratory (UWRL) at Utah State University has developed a new remote sensing platform called "AggieAir™" to deal with these shortcomings in order to provide access to remote sensing data for more applications. The AggieAir platform, consisting of a low-cost UAV that is fully autonomous, easy to use, and independent of a runway, was utilized for this project. Aggie Air can acquire imagery very quickly and with a high spatial resolution. For more information on AggieAir, refer to http://aggieair.usu.edu/.

Mock Flood Demonstration

A mock flood demonstration of the capabilities of the UAV was conducted on February 8, 2011 on the Bear River near Cache, Utah, a location at which the UWRL has a certificate of authorization from the FAA to conduct UAV flights. The flight path of the UAV focused on the stretch of the river that included the bridge crossing of Utah Highway 26 (see Figure 1).

Figure 1: Satellite Photo from Google Maps

Unfortunately, the schedules of the participating governmental emergency responders required the demonstration to be conducted during the winter. Low temperatures prevailed with both snow on the ground and ice in the river. However, the demonstration clearly showed the capability of the UAV to produce high resolution photos of bridge crossings, sediment deposits, debris, and the river banks (see Figure 2 for an example image that was taken by AggieAir during this demonstration and Figure 3 for the entire set of images acquired during the demonstration). Following the flight demonstration, a meeting was held to present the flight photographs and to discuss the benefits and uses of the UAV for flood response. Those attending the meeting included: Justin Maughan, Lance Houser, and Will Luck from Logan City; Deewey Cragun and Kirk Freeman from Ogden City; Dave Cole from the Utah Division of Water Resources; James Greer and Jared Manning from the Utah Division of Water Rights; and Jake Peterson and Darin Hawes from Cache County Search and Rescue.

Figure 2: February 8, 2011 AggieAir Photo of the Utah Highway 23 Bridge

Figure 3: Area Photographed During the February 8, 2011 UAV Flight (images shown along the channel banks and at bridge crossings overlaid on a Google Earth base map)

The meeting discussion focused on the capabilities of the UAV to meet the following objectives:

- Detecting and qualifying debris at bridges.
- Detecting and qualifying debris at culverts.
- Monitoring the stability of road crossings and bridges.
- Detecting and qualifying sediment aggredation and build-up of sediment
- Detection of channel banks and levees at risk.
- Detection of canal and levee leakage.
- Detection of homes, buildings, and other type of structures at risk.
- Detection of vehicles and pedestrians.
- Detection of occupied homes and vehicles.
- Monitoring detention basins, holding ponds, and release structures.
- Monitoring and assessing damage to critical infrastructures such as gas lines and power lines.
- Detection of flood victims.
- Monitoring of emergency response personnel and assets.
- Detection and monitoring of pre-programmed dwellings, road crossings, banks, canals, infrastructure, and any structures and property at risk for flood events.

Discussions further emphasized the need and ability of the UAV to monitor flood debris; monitor water surface levels at bridges and other critical structures; monitor sediment scour and deposition, especially bank caving; aide in victim and property recovery; and identify and monitor potential oil leaks, broken oil and gas lines, downed power lines, and loose propane tanks. The ability to survey and monitor power lines and natural gas leaks with a UAV following a flood or earthquake is a significant need because of the danger to ground personnel. The decided was also made during the meeting that some type of autonomous vertical takeoff aircraft is needed for bridge inspection during a flood event.

Saint George, Utah Meeting

On December 21, 2010 the Santa Clara River flooded for the second time in five years. Channel improvements made following the 2005 flood helped protect some homes and public utilities, but unexpected debris endangered a number of bridges and road crossings (Figure 4). Following the February 8 mock flood demonstration, a meeting in St. George was held with Jay Sandberg from the City of St. George and Rick Rosenberg of Rosenberg and Associates to discuss the results of the UAV demonstration and to evaluate the application of the UAV for flood events such as the 2010 Santa Clara River flood.

Figure 4: December 2010 Flooding in St. George, Utah

Discussions again emphasized the need to monitor debris at bridges and culverts but also highlighted the need to prioritize areas for flood debris removal following a flood event. Further discussion of debris brought up the need to identify and inventory areas of potential debris sources. Pre-flood debris removal would significantly reduce flood damage. Removing the debris at the source would also be more economical and pose significantly less risk to personnel than removing debris at a bridge during a flood.

One of the most significant needs identified in the St. George meeting was the use of a UAV to conduct a visual survey and assessment of flood damage to public and private property. This type of survey is conducted in a 30-day period following a flood event and is the basis for determining government aid for flood damage. The survey needs to be detailed and thorough because damage reported after the 30-day period is not eligible for federal or state aid. A flood damage survey is almost impossible to perform from the ground; typically, small planes or helicopters are used to photograph flood damage. Such aerial surveys are expensive, and time does not allow enough coordinated ground surveys to produce geo-referenced maps of the flood damage.

The use of the UAV to perform a post 30-day flood damage survey would be a significant improvement over the typical aerial surveys, especially at the typical geographic scale of many floods in Utah and the Intermountain West. Not only would the UAV survey be much more economical, the survey would produce detail geo-referenced maps. The maps would be available in a short enough time frame so that additional UAV flights, if needed, could be performed. It is not clear which City, State, or Federal agency is financially responsible for a post-flood damage survey; however, the inexpensive cost of a UAV survey would allow any city or county agency to perform their own surveys without having to wait for Federal or State agencies to arrange for and to pay for the surveys.

The use of a UAV for post-flood damage assessment and surveys is a significant benefit for flood emergency response. It is recommended that FEMA and other Federal agencies be contacted about the use of the UAV to begin a much broader program that will be nationally accepted using UAVs for flood damage assessment.

Developing a Priority System for Managing Sediment in Smaller Reservoirs

Basic Information

Title:	Developing a Priority System for Managing Sediment in Smaller Reservoirs
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Focus Category:	Sediments, Treatment, Water Quality
Descriptors:	Reservoir sedimentation, prediction equation
Principal Investigators:	Rollin Hotchkiss

Publications

There are no publications.

Developing a Priority System for Managing Sediment in Smaller Reservoirs

Rollin H. Hotchkiss

Contents

Contents 1
List of Tables 1
List of Figures 1
List of Equations 1
Introduction 2
Data Collection 2
Methods and Results 6
    Causey Survey Results 8
Discussion of Results 8
Conclusion 9
Appendix 10
    References 11
    Attempt 1 12
    Attempt 2 15
    Attempt 3 19
    Variables 24

List of Tables

Table 1: Variables Found Using ArcGIS 3
Table 2: Sample of Land use Values for Watersheds, Expressed in Percent 4
Table 3: Precipitation Averages over Watershed, Expressed in Inches 4
Table 4: Average Soil Characteristics for each Watershed 5
Table 5: Statistical Attempts and Results 6
Table 6: Attempt 3 Parameter Estimates 7

List of Figures

Figure 1: Actual Sedimentation Rate vs. Predicted 7

List of Equations

Percent Annual Capacity Loss = f (variable 1, variable 2 …) (1) 2
Log Sedimentation Rate (2) 8

Introduction

Due to the large number of reservoirs in Utah and the necessity of maintaining water supplies for the population, it has been proposed to develop a system of prioritizing reservoirs in Utah to direct sediment management actions. Seventeen reservoirs were initially looked at to develop a system of predicting sedimentation in reservoirs based on natural factors and specific reservoir characteristics. Variables have been researched and compiled for each reservoir from several different data sets and were used in a statistical analysis to determine which variables significantly affect the sedimentation of reservoirs in Utah.

To determine whether a reservoir should be surveyed, an equation predicting the sedimentation rate of individual reservoirs was developed based on variables from the reservoir and corresponding watershed, the general form is shown in Equation 1. The sedimentation rate, expressed in percent annual capacity loss, can then be used to determine whether or not the reservoir should be surveyed.

$$\% \text{ Annual Capacity Loss} = f\,(\text{variable 1, variable 2} \ldots) \tag{1}$$

Data Collection

Several parameters were identified as possible variables to be used in the sedimentation prediction equation. The initial variable list included precipitation, stream order, 50 year peak discharge, erodibility index, geologic characteristics, average basin slope, basin area, land use, along with variables of the dam and reservoir including the dead storage volume quantity and trapping efficiency. Data concerning the sedimentation rates and reservoir characteristics were found in the Utah Division of Water Resources' *Managing Sediment in Utah's Reservoirs*. The entire database of variables is found in the Appendix.

All variables were determined using data sets available from different government agencies. ArcGIS was used to further define several variables for each individual reservoir watershed. Initially, the watershed was mapped using both StreamStats, provided through the U.S. Geological Survey (USGS); and ArcGIS with data from the National Map Seamless Server, also made available by the USGS. A Digital Elevation Model (DEM) from the National Elevation Dataset with a 1 arc second resolution was used with several Hydrology tools within Spatial Analyst toolbox in ArcMap to delineate the watershed basin corresponding to each reservoir.

The delineated basins were then compared to ensure validity and proper drainage basin size. The delineated basins enabled maximum elevation, average elevation, and slope characteristics to be determined from the DEM. The hydrology tools in ArcMap were also used to outline the river system of each watershed to determine the stream order using the Strahler method. All of the variables resulting from analysis in ArcGIS are found in Table 1. The peak flows were taken from the watersheds delineated using StreamStats.

TABLE 1: Variables Found Using ArcGIS

Reservoir	Max Slope (%)	Mean Slope (%)	Stream Order	Max Elevation (m)	Average Elevation (m)
Causey	67.19	19.10	3	2783	2291
East Canyon	58.02	15.10	3	9071	2146
Echo	68.27	13.79	4	3636	2345
Gunlock	66.62	14.03	4	3161	1836
Hyrum	63.20	15.70	4	2868	2002
Lake Powell	89.83	8.89	7	4393	2150
Millsite	66.90	13.97	4	3400	2692
Otter Creek	68.66	10.79	4	3543	2433
Piute	73.45	10.30	5	3543	2452
Rocky Ford	65.20	11.20	4	3704	2240
Scofield	51.24	15.30	3	3183	2624
Sevier Bridge	75.22	11.38	5	3705	2291
Starvation	67.80	14.30	5	3226	2390
Steinaker	57.25	10.37	2	2366	1835
Upper Enterprise	48.43	13.40	2	2286	1923
Wanship	72.67	15.37	4	3632	2497
Wide Hollow	49.50	9.99	2	2349	1975
Yankee Meadows	58.50	12.97	1	3224	2889

The delineated basins were also used to determine several other characteristics of the watershed. Several data sets were downloaded from the Natural Resources Conservation Service's Geospatial Data Gateway including the National Land Cover Dataset (2001), STATSGO data, Annual and Monthly Average Precipitation, and Geology datasets. All of the datasets from the Geospatial Data Gateway were imported into ArcGIS and overlaid with the watershed. The individual averages and characteristics were then determined for each dataset.

The land cover, sample shown in Table 2, and geology data are expressed in percent composition of the watershed. While the precipitation, shown in Table 3, and soil data are averages over the watershed area. The STATSGO data was used to find three soil related characteristics of the watershed including the hydrologic soil group, an erodibility factor (K_w), and the soil loss tolerance factor (T factor), all shown in Table 4.

TABLE 2: Sample of Land use Values for Watersheds, Expressed in Percent

Reservoir	Open Water	Barren Land (Rock/ Sand/Clay)	Deciduous Forest	Evergreen Forest	Mixed Forest	Shrub/ Scrub	Grassland/ Herbaceous	Pasture/ Hay
Causey	0.19	0.01	67.20	16.42	1.02	14.93	0.02	0.03
East Canyon	0.65	0.04	48.14	13.74	0.52	30.53	0.01	1.09
Echo	0.60	1.15	37.06	22.45	1.25	30.42	0.55	3.76
Gunlock	0.08	0.02	0.54	56.01	0.83	39.35	0.94	1.29
Hyrum	0.38	0.01	40.22	13.68	0.84	34.37	0.24	5.47
Lake Powell	0.56	5.24	7.01	20.88	0.72	51.75	9.19	2.14
Millsite	0.39	3.84	11.75	34.89	6.70	35.35	5.80	0.06
Otter Creek	0.77	0.17	8.06	32.62	4.02	49.88	0.50	1.18
Piute	0.35	1.60	3.17	47.18	3.96	39.38	0.71	1.19
Rocky Ford	0.17	0.56	4.09	46.05	4.74	36.96	1.35	3.22
Scofield	2.66	0.14	42.86	19.04	2.52	31.15	0.39	0.00
Sevier Bridge	0.51	1.38	7.27	41.58	3.08	38.00	0.94	3.28
Starvation	2.60	4.13	24.04	29.20	1.39	36.73	0.11	0.71
Steinaker	4.24	5.19	0.06	29.63	0.01	54.56	0.18	3.45
Upper Enterprise	1.17	0.01	5.45	75.33	0.00	17.84	0.02	0.03
Wanship	0.67	2.27	30.72	36.06	1.38	20.32	0.72	5.38
Wide Hollow	1.58	3.23	0.00	42.44	0.00	50.77	0.76	0.89
Yankee Meadows	5.33	1.85	0.21	47.40	41.90	2.51	0.00	0.00

TABLE 3: Precipitation Averages over Watershed, Expressed in Inches

Reservoir	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
Causey	4.0	3.2	3.6	3.3	3.0	1.5	1.1	1.5	2.5	2.5	3.4	3.6	32.8
East Canyon	2.9	2.8	3.1	2.6	2.5	1.5	1.2	1.4	1.7	2.5	2.9	2.3	27.1
Echo	2.6	2.5	2.7	2.8	2.6	1.5	1.4	1.4	1.7	2.1	2.6	2.2	25.9
Gunlock	2.0	2.4	2.8	1.4	1.1	0.5	0.9	1.6	1.3	1.6	1.6	1.5	18.9
Hyrum	3.6	3.3	3.4	2.9	3.0	1.5	1.3	1.5	2.1	2.5	3.1	3.2	31.3
Lake Powell	1.2	1.1	1.4	1.3	1.4	0.8	1.3	1.3	1.3	1.5	1.2	1.1	15.6
Millsite	2.6	2.5	2.8	2.0	2.0	1.0	1.5	1.9	1.9	2.1	2.4	2.0	24.3
Otter Creek	1.4	1.4	2.0	1.5	1.4	0.6	1.4	1.6	1.4	1.5	1.4	1.2	17.2
Piute	1.6	1.7	2.1	1.3	1.3	0.6	1.5	1.9	1.5	1.8	1.5	1.2	18.3
Rocky Ford	1.6	1.6	2.3	1.9	1.8	0.7	1.5	1.8	1.6	1.7	1.5	1.3	19.2
Scofield	2.5	2.5	2.7	2.1	1.8	1.0	1.4	1.5	1.8	2.3	2.2	2.0	23.7
Sevier Bridge	1.6	1.6	2.1	1.5	1.5	0.6	1.3	1.6	1.4	1.8	1.6	1.3	18.1
Starvation	2.1	1.9	2.0	1.6	1.5	1.0	1.4	1.8	1.7	1.9	2.1	1.7	20.8
Steinaker	0.5	0.5	0.7	1.0	1.5	0.6	0.6	0.6	1.4	1.5	0.5	0.5	10.8
Upper Enterprise	3.0	3.9	3.5	1.5	1.5	0.5	1.3	1.5	1.5	2.2	2.3	2.4	24.5
Wanship	3.1	3.0	3.3	3.3	2.8	1.4	1.5	1.5	1.9	2.3	3.0	2.6	29.8
Wide Hollow	0.9	0.7	1.2	0.5	0.5	0.5	0.8	1.5	1.5	1.5	0.5	0.5	11.4
Yankee Meadows	3.3	3.5	4.3	2.5	1.5	0.5	1.7	2.5	2.2	2.5	2.5	2.5	30.5

TABLE 4: Average Soil Characteristics for each Watershed

Reservoir	Hydrologic Soil Group	Kw	T Factor
Causey	B	0.32	4
East Canyon	C	0.32	3
Echo	C	0.32	3
Gunlock	D	0.24	1
Hyrum	C	0.37	3
Lake Powell	C	0.26	3
Millsite	C	0.35	2
Otter Creek	B	0.33	3
Piute	C	0.32	3
Rocky Ford	B	0.31	3
Scofield	C	0.31	3
Sevier Bridge	C	0.32	3
Starvation	C	0.29	3
Steinaker	D	0.18	1
Upper Enterprise	D	0.36	2
Wanship	C	0.31	3
Wide Hollow	C	0.27	2
Yankee Meadows	C	0.29	4

Several reservoirs are managed by the Bureau of Reclamation (BOR) and have daily inflow values. Some data were initially received from the BOR through an email; however other values were gathered from the website as needed. Several reservoirs have stream gauges upstream maintained by the USGS. These gauges were used to estimate annual inflow into the reservoir. Most reservoirs had gauges close to the outlet of the major stream or river; however, some reservoirs do not appear to have stream gauges located in appropriate locations for the data to be used as the total inflow. The inflow values for those reservoirs were approximated based on the curve number of the watershed and monthly precipitation values. The reservoir inflow values and capacity were then used with Brune's curve to determine the trap efficiency of each reservoir (Gregory L. Morris, 1997). The median curve was used for all the reservoirs and the trap efficiency percentage ranged from 90% to 98%.

Several dam characteristics were considered for use in the statistical equation. Due to the nature of statistical analysis only numerical values are considered unless numbers can be assigned to represent values. The storage capacity, surface area, and the date built from *Managing Sediment in Utah's Reservoirs*, are included along with all the other variables in the statistical model.

Methods and Results

After all the data had been organized in a spreadsheet, the values were inputted into JMP9, a statistical program. All of the data were examined using a scatter plot matrix to ensure linearity and were transformed using log transformations if sufficient linearity was not apparent. Lake Powell was identified as an outlier and after considering the statistical implications of including it in the data set, the reservoir was excluded to improve the results. A stepwise regression using a mixed data selection process (p-value of 0.15) was performed to identify key variables on the transformed data. The model produced by the stepwise regression could then be used to generate a simple linear regression model. Several attempts were made to develop a model. Table 5 shows the variables identified according to attempt and the resulting coefficients.

TABLE 5: Statistical Attempts and Results

Attempt	Adjusted R^2 (%)	Variables Used	Coefficients Calculated
1	92%		
		Log(10 Year Peak Flow) (ft^3/s)	-0.298953
		Average Elevation (m)	0.000706
		July Precipitation (in)	-1.793973
		August Precipitation (in)	0.930434
		Mudstone (%)	-0.016591
		Water (%)	-0.165989
2	99%		
		Log(Surface Area) (acres)	-0.175511
		Deciduous Forest (%)	-0.027140
		Woody Wetlands (%)	0.860184
		Ash-Flow Tuff Basalt (%)	-0.007164
		Conglomerate Sandstone (%)	0.183710
		Mudstone Conglomerate (%)	-0.012479
		Mudstone Siltstone (%)	-0.231267
		Shale Limestone (%)	-0.009215
3	99%		
		Storage Capacity (ac-ft)	-0.101254
		Kw	-6.535776
		June Precipitation (in)	-0.183626
		July Precipitation (in)	-0.245008
		Barren Land (%)	0.156366
		Fine Grained Mixed Clastic Limestone (%)	-0.016041
		Sandstone Mudstone (%)	-0.008052
		Shale Limestone (%)	-0.048389
		Shale Siltstone (%)	-0.142314

The details of the latest attempt can be found in Table 6. Using the parameter estimates, a plot of the actual log sedimentation rate by predicted was developed and is shown in Figure 1; the red dotted lines representing the 95% confidence intervals. The R squared adjusted value for this analysis is 0.977043.

TABLE 6: Attempt 3 Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|	Lower 95%	Upper 95%
Intercept	1.7487235	0.229259	7.63	<.0001	1.220052	2.277395
LOG Storage Capacity (ac-ft)	-0.069564	0.033819	-2.06	0.0737	-0.147549	0.008422
Kw	-6.025869	0.702487	-8.58	<.0001	-7.645806	-4.405933
June	-0.204307	0.067476	-3.03	0.0164	-0.359906	-0.048708
Barren Land (Rock/ Sand/Clay)	0.1327033	0.017126	7.75	<.0001	0.093212	0.172195
fine-grained mixed clastic limestone	-0.018747	0.007164	-2.62	0.0308	-0.035267	-0.002226
shale limestone	-0.0793	0.00766	-10.35	<.0001	-0.096965	-0.061636
shale siltstone	-0.128632	0.006922	-18.58	<.0001	-0.144594	-0.112669

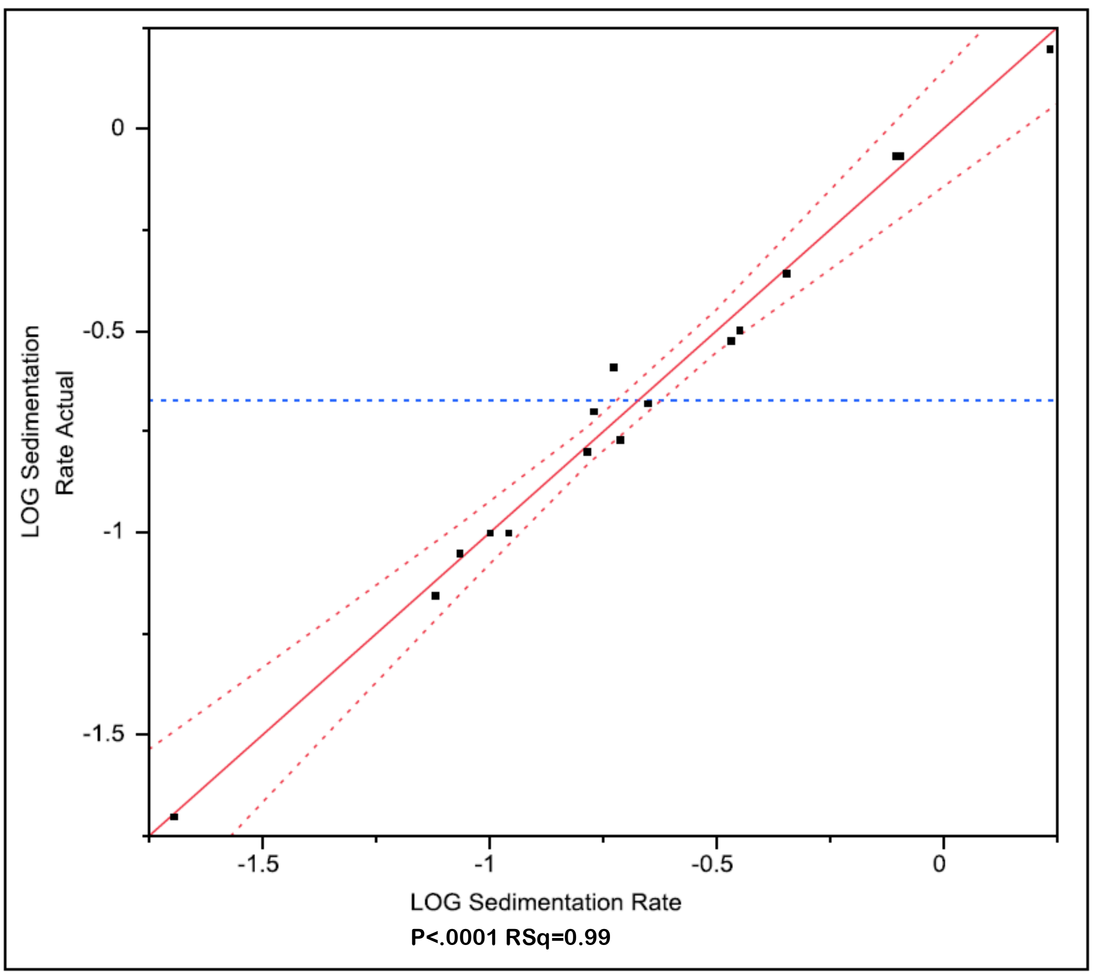

FIGURE 1: Actual Sedimentation Rate vs. Predicted

The resulting equation, Equation 2, is shown below. The complete statistical analysis can be found the Appendix.

$$Log(Sedimentation\ Rate) = 1.749 - 0.069564(Log(Storage\ Capacity)) - 6.026(K_w) - 0.2043(June) + 0.1327(Barren\ Land) - 0.01874(Fine\ Grained\ Mixed\ Clastic\ Limestone) - 0.0793(Shale\ Limestone) - 0.1286(Shale\ Siltstone) \quad (2)$$

Where:

Storage Capacity = Initial storage capacity of reservoir (acre-ft)
Kw= Weighted average Kw factor over the reservoir watershed
June = Average June precipitation for reservoir watershed (in)
Barren Land = Area of watershed covered by barren land (%)
Fine Grained Mixed Clastic Limestone = Area of watershed covered by Fine Grained Mixed Clastic Limestone (%)
Shale Limestone = Area of watershed covered by Shale Limestone (%)
Shale Siltstone = Area of watershed covered by Shale Siltstone (%)

Causey Survey Results

In June 2010, a bathymetric survey was conducted for Causey reservoir in Weber County, Utah. At that time the water elevation was at spillway elevation making the reservoir level optimum for conducting a bathymetric survey. After the survey was completed the raw data was processed to eliminate any points not consistent with the existing topographic maps. The processed data were then loaded into ArcGIS and a raster was created to determine the amount of settlement that has occurred. It was found that the reservoir has approximately 97.6 ac-ft of sediment from the time of construction, results shown in the Appendix. The sedimentation rate was found to be 0.034%, a very low sedimentation rate comparatively.

The equation was used with data for Causey reservoir to determine which equation best predicted the actual sedimentation present. The predicted sedimentation rate using the above equation is 0.181% (0.111% to 0.295%) annual capacity loss.

Discussion of Results

Due to the large number of variables and the small data set, all 16 reservoirs were used to develop the equation. Even while using the entire data set to develop a linear regression, the large number of variables could easily force the R-squared value to 100%. To counteract this, random variables were used and the stepwise process was stopped before the R square value reached 100% or a random variable was included. The equation appears to fit the data reasonably; however, there is some concern regarding which variable types are represented and the weight of the variables.

The equation contains variables primarily from the soil, geology, and land use data sets. The K_w value is the most heavily weighted with a coefficient of 6.03 indicating that the equation is sensitive to that particular value. It seems reasonable that the sedimentation in a reservoir is driven primarily by the erodibility of the soil. The geology terms also contribute in a similar way: the chosen geology classifications are all sedimentary rocks with higher potential for erosion.

During the statistical analysis, some variables were removed from the equation; however, these variables may be more significant than determined by the analysis. Potentially important variables include reservoir characteristics and inflow values. Because of this concern the inflow values were recalculated to ensure validity. Several of the inflow values were estimated using weighted curve number and hydrologic number. Monthly precipitation averages were used to estimate total annual average runoff. This method introduces the possibility of a large amount of error in the analysis. The inflow values were used primarily for estimating trapping efficiency of the reservoir. However, the trapping efficiencies for each reservoir are fairly similar limiting the possibility that it would be a significant variable. Storage Capacity was determined to be significant enough to include in the final model, however, that is the only reservoir characteristic included.

Another concern pertains to the coefficient values: the reasonableness of the sign. If the coefficient is positive then it is contributing to the sedimentation rate. The storage capacity and barren land percentage reduce and contribute to sedimentation, respectively. These conclusions appear to be consistent with accepted ideas. However, if this holds true then the increase of the erodibility factor causes the reservoir sedimentation to decrease. It is possible that the variable may not work in the equation as expected, possibly due to the relationship with the intercept values.

Though the equation developed was not accurate in predicting the actual sedimentation rate of Causey reservoir, it did give an estimate that was in the low range of values indicating that the reservoir is not in immediate danger of filling up with sediment. This equation can be used to predict sedimentation, however, the results vary greatly and it is possible that reservoirs will high sedimentation will not be identified. Using the predicted sedimentation rate and other characteristics, such as intended use, hazard rating, age and storage capacity, etc., each reservoir risk can be ranked as severe, moderate, or small. This will give very rough guidelines largely defined by the user. To fully develop a model that will be effective at predicting reservoir sedimentation, a much larger dataset is required. The statistical analysis of so little data points cannot be expected to produce results applicable to all the reservoirs in the state. A prediction of sedimentation can be calculated using this equation, however, other characteristics known about the reservoir should be relied on to make the final decision about which reservoirs should be surveyed and monitored.

Conclusion

The variables for the reservoir have been gathered and after statistical analysis, several variables have been identified as potentially significant. After preliminary results were evaluated, the variables and resulting equation provided possess the highest statistical significance and validity for the dataset given. Due to the small dataset, the equation is tailored to predict the sedimentation values of the reservoirs within the dataset but does not prove as accurate when applied to other data points. This equation should not be relied upon to decide which reservoirs are in need of surveying but should be used in the consideration with other variables to assess which reservoirs are in danger of sedimentation.

Appendix

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Attempt 1

Stepwise Fit for LOG Sedimentation Rate

Stepwise Regression Control

Stopping Rule:

Prob to Enter	0.15
Prob to Leave	0.15

Direction:

1 rows not used due to excluded rows or missing values.

SSE	DFE	RMSE	RSquare	RSquareAdj	Cp	p	AICc	BIC
0.1654562	9	0.1355877	0.9502	0.9170	.	7	8.83126	-5.55946

Current Estimates

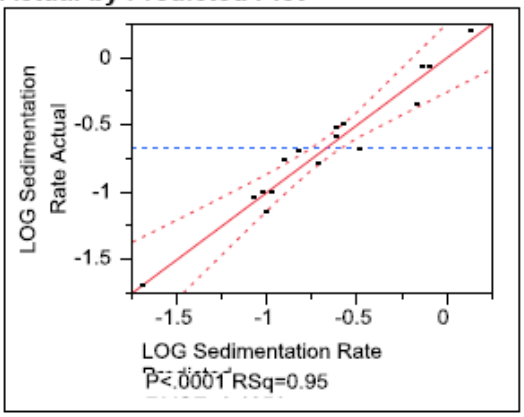
Lock	Entered	Parameter	Estimate	nDF	SS	"F Ratio"	"Prob>F"
X	X	Intercept	-0.2015257	1	0	0.000	1
		Random1	0	1	0.001192	0.058	0.81564
		Random2	0	1	0.021471	1.193	0.30653
		Random3	0	1	0.003455	0.171	0.69043
		Random 4	0	1	0.000551	0.027	0.87414
		Date Built	0	1	6.653e-5	0.003	0.95615
		LOG Storage Capacity (ac-ft)	0	1	0.000724	0.035	0.85594
		Mean Annual Precipitation (in)	0	1	0.011024	0.571	0.47149
		Average Basin Slope (%)	0	1	0.000748	0.036	0.85362
		Mean Basin Elevation (ft)	0	1	0.000786	0.038	0.84995
		LOG Peak Flow 2 ft^3/s	0	1	0.007	0.353	0.56863
		LOG Peak Flow 5 ft^3/s	0	1	0.037844	2.372	0.16206
	X	LOG Peak Flow 10 ft^3/s	-0.2989535	1	0.229038	12.459	0.00642
		LOG Peak Flow 25 ft^3/s	0	1	0.023157	1.302	0.28687
		LOG Peak Flow 50 ft^3/s	0	1	0.016158	0.866	0.37934
		LOG Peak Flow 100 ft^3/s	0	1	0.00742	0.376	0.55697
		LOG Peak Flow 200 ft^3/s	0	1	0.006247	0.314	0.59063
		LOG Peak Flow 500 ft^3/s	0	1	0.004002	0.198	0.6679
		Hydrologic Number	0	1	0.000775	0.038	0.851
		Kw	0	1	0.030866	1.835	0.21259
		T Factor	0	1	0.02159	1.201	0.3051
		Max Slope (%)	0	1	0.003855	0.191	0.67377
		Mean Slope (%)	0	1	0.000115	0.006	0.94231
X	X	Stream Order	0	1	0.047006	3.175	0.11265
		LOG Max Elevation (m)	0	1	0.000277	0.013	0.9106
	X	Average Elevation (m)	0.00070588	1	0.178419	9.705	0.01241
		January	0	1	0.001773	0.087	0.77598
		February	0	1	0.000711	0.035	0.85725
		March	0	1	0.007824	0.397	0.54617
		April	0	1	0.022858	1.282	0.29026
		May	0	1	0.003568	0.176	0.68563
		June	0	1	0.00344	0.170	0.69106
	X	July	-1.7939729	1	0.692649	37.677	0.00017
	X	August	0.93043411	1	0.580542	31.579	0.00033
		September	0	1	0.011926	0.621	0.45324
		October	0	1	0.016744	0.901	0.37037
		November	0	1	0.000043	0.002	0.96477
		December	0	1	0.000778	0.038	0.85067
		Annual	0	1	0.006331	0.318	0.58811

Lock	Entered	Parameter	Estimate	nDF	SS	"F Ratio"	"Prob>F"
		Open Water	0	1	0.022666	1.270	0.29246
		Perennial Ice/Snow	0	1	0.002048	0.100	0.75964
		Developed, Open Space	0	1	0.002309	0.113	0.74517
		Developed, Low Intensity	0	1	0.002811	0.138	0.71965
		Developed, Medium Intensity	0	1	0.002023	0.099	0.76105
		Developed, High Intensity	0	1	0.000413	0.020	0.891
		Barren Land (Rock/ Sand/Clay)	0	1	0.014081	0.744	0.41343
		Deciduous Forest	0	1	0.005692	0.285	0.60794
		Evergreen Forest	0	1	3.754e-6	0.000	0.98958
		LOG+1Mixed Forest	0	1	0.001714	0.084	0.77965
		Shrub/ Scrub	0	1	0.025911	1.485	0.25764
		LOG+1Grassland/ Herbaceous	0	1	0.011637	0.605	0.45899
		Pasture/ Hay	0	1	0.030263	1.791	0.21761
		Cultivated Crops	0	1	0.002203	0.108	0.75093
		Woody Wetlands	0	1	0.000241	0.012	0.91658
		alluvium 2	0	1	0.01189	0.619	0.45395
		arenite 2	0	1	0.022634	1.268	0.29282
		ash-flow tuff	0	1	0.010267	0.529	0.48767
		basalt	0	1	0.005865	0.294	0.60243
		carbonate	0	1	0.000575	0.028	0.87144
		clay or mud	0	1	0.000575	0.028	0.87144
		conglomerate	0	1	0.008378	0.427	0.53193
		dacite	0	1	0.010989	0.569	0.47222
		dolostone (dolomite)	0	1	0.001962	0.096	0.76461
		fine-grained mixed clastic	0	1	0.018321	0.996	0.34748
		glacial drift 2	0	1	0.001309	0.064	0.80697
		landslide	0	1	1.132e-5	0.001	0.98191
		limestone 2	0	1	0.000122	0.006	0.9407
		medium-grained mixed clastic	0	1	0.006307	0.317	0.58882
	X	mudstone	-0.0165909	1	0.239703	13.039	0.00565
		quartz monzonite	0	1	0.007886	0.400	0.54455
		rhyolite	0	1	0.008953	0.458	0.51779
		sandstone 2	0	1	0.000353	0.017	0.89917
		shale	0	1	0.003586	0.177	0.68485
		volcanic rock (aphanitic) 2	0	1	0.007186	0.363	0.56341
	X	water 2	-0.1659891	1	0.908805	49.434	6.11e-5
		LOG Drainage Area mi^2	0	1	0.003374	0.167	0.6939

Step History

Step	Parameter	Action	"Sig Prob"	Seq SS	RSquare	Cp	p	AICc	BIC
1	August	Entered	0.0063	1.40763	0.4236	.	2	19.4411	19.7588
2	July	Entered	0.0119	0.759272	0.6521	.	3	14.9982	14.4522
3	water 2	Entered	0.0170	0.450307	0.7877	.	4	11.4638	9.32677
4	Average Elevation (m)	Entered	0.0670	0.192627	0.8456	.	5	11.6954	6.99759
5	Evergreen Forest	Entered	0.0384	0.185795	0.9016	.	6	11.1654	2.57353
6	Stream Order	Entered	0.0366	0.131012	0.9410	.	7	11.55	-2.8407
7	mudstone	Entered	0.0510	0.077767	0.9644	.	8	14.8967	-8.15
8	Evergreen Forest	Removed	0.9315	0.000116	0.9644	.	7	3.48389	-10.907
9	Pasture/ Hay	Entered	0.0967	0.036329	0.9753	.	8	9.0517	-13.995
10	Stream Order	Removed	0.0006	0.310596	0.8818	.	7	22.6614	8.27068
11	Pasture/ Hay	Removed	0.8446	0.001777	0.8813	.	6	14.1622	5.57031
12	LOG Peak Flow 10 ft^3/s	Entered	0.0064	0.229038	0.9502	.	7	8.83126	-5.5595

Response LOG Sedimentation Rate
Actual by Predicted Plot



Summary of Fit

RSquare	0.950205
RSquareAdj	0.917008
Root Mean Square Error	0.135588
Mean of Response	-0.67084
Observations (or Sum Wgts)	16

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	6	3.1572885	0.526215	28.6235
Error	9	0.1654562	0.018384	**Prob> F**
C. Total	15	3.3227447		<.0001*

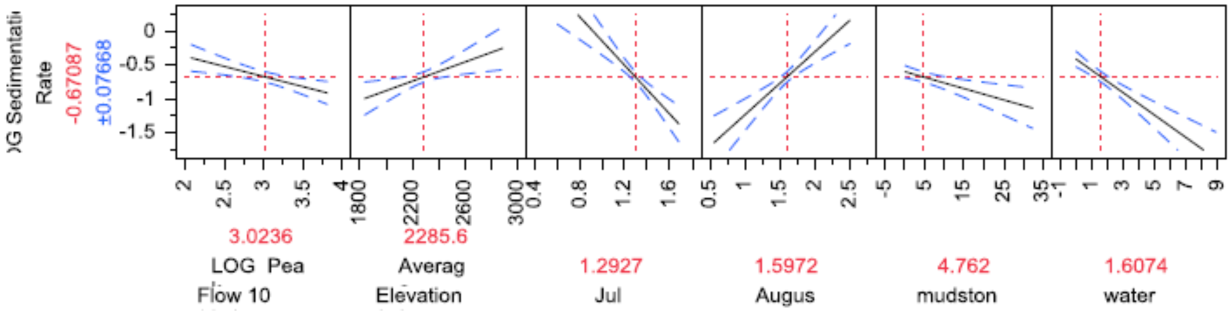
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-0.201526	0.402676	-0.50	0.6288
LOG Peak Flow 10 ft^3/s	-0.298953	0.084697	-3.53	0.0064*
Average Elevation (m)	0.0007059	0.000227	3.12	0.0124*
July	-1.793973	0.292267	-6.14	0.0002*
August	0.9304341	0.165573	5.62	0.0003*
mudstone	-0.016591	0.004595	-3.61	0.0057*
water 2	-0.165989	0.023608	-7.03	<.0001*

Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	t Ratio	Prob>|t|
water 2	-0.165989	0.023608	-7.03		<.0001*
July	-1.793973	0.292267	-6.14		0.0002*
August	0.9304341	0.165573	5.62		0.0003*
mudstone	-0.016591	0.004595	-3.61		0.0057*
LOG Peak Flow 10 ft^3/s	-0.298953	0.084697	-3.53		0.0064*
Average Elevation (m)	0.0007059	0.000227	3.12		0.0124*

Prediction Profiler



Attempt 2

Stepwise Fit for LOG Sedimentation Rate

Stepwise Regression Control

Stopping Rule:

Prob to Enter	0.15
Prob to Leave	0.15
Direction:	

1 rows not used due to excluded rows or missing values.

SSE	DFE	RMSE	RSquare	RSquareAdj	Cp	p	AICc	BIC
0.0120909	7	0.0415604	0.9964	0.9922	.	9	-5.60026	-41.8744

Current Estimates

Lock	Entered	Parameter	Estimate	nDF	SS	"F Ratio"	"Prob>F"
X	X	Intercept	0.2855886	1	0	0.000	1
		Random1	0	1	1.468e-6	0.001	0.97934
		Random2	0	1	1.867e-5	0.009	0.92639
		Random3	0	1	0.004339	3.359	0.11656
		Random 4	0	1	0.00306	2.033	0.20382
		Date Built	0	1	0.000014	0.007	0.93623
		LOG Storage Capacity (ac-ft)	0	1	0.003121	2.087	0.19865
		LOG Drainage Area mi^2	0	1	0.006114	6.138	0.04797
		Mean Annual Precipitation (in)	0	1	0.003859	2.813	0.1445
		Average Basin Slope (%)	0	1	0.000819	0.436	0.53357
		Mean Basin Elevation (ft)	0	1	0.001374	0.769	0.41425
		Area Covered by Herbaceous Upland (%)	0	1	0.002794	1.803	0.22793
		SquareRoot Area Covered by Herbaceous Upland (%)	0	1	0.00427	3.275	0.12031
		LOG Peak Flow 2 ft^3/s	0	1	0.007374	9.381	0.02214
		LOG Peak Flow 5 ft^3/s	0	1	0.006762	7.612	0.0329
		LOG Peak Flow 10 ft^3/s	0	1	0.006308	6.545	0.04301
		LOG Peak Flow 25 ft^3/s	0	1	0.005834	5.595	0.05588
		LOG Peak Flow 50 ft^3/s	0	1	0.005629	5.227	0.06226
		LOG Peak Flow 100 ft^3/s	0	1	0.005157	4.462	0.07911
		LOG Peak Flow 200 ft^3/s	0	1	0.004755	3.889	0.09608
		LOG Peak Flow 500 ft^3/s	0	1	0.00425	3.253	0.12136
	X	LOG Surface Area (acres)	-0.1755114	1	0.050741	29.377	0.00099
		LOG Annual Average Flow (ac-ft/yr)	0	1	0.009483	21.816	0.00343

Lock	Entered	Parameter	Estimate	nDF	SS	"F Ratio"	"Prob>F"
		Hydrologic Number	0	1	0.007727	10.625	0.01726
		Kw	0	1	6.084e-5	0.030	0.86744
		T Factor	0	1	0.00027	0.137	0.72418
		Max Slope (%)	0	1	0.004514	3.575	0.10754
		Mean Slope (%)	0	1	0.004407	3.441	0.11299
		Stream Order	0	1	0.007644	10.314	0.01833
		LOG Max Elevation (m)	0	1	0.003677	2.622	0.15652
		Average Elevation (m)	0	1	0.001193	0.657	0.44855
		January	0	1	0.004714	3.834	0.09797
		February	0	1	0.006835	7.802	0.03144
		March	0	1	0.005062	4.321	0.08288
		April	0	1	1.036e-6	0.001	0.98264
		May	0	1	0.000369	0.189	0.67893
		June	0	1	0.003754	2.701	0.15136
		July	0	1	0.000565	0.294	0.60725
		August	0	1	0.000142	0.071	0.79872
		September	0	1	0.000848	0.452	0.52626
		October	0	1	0.005755	5.449	0.05829
		November	0	1	0.00212	1.276	0.30179
		December	0	1	0.004163	3.150	0.12626
		Annual	0	1	0.002577	1.625	0.24952
		Open Water	0	1	0.007439	9.596	0.02118
		Perennial Ice/Snow	0	1	0.003784	2.733	0.14939
		Developed, Open Space	0	1	0.004731	3.857	0.09717
		Developed, Low Intensity	0	1	0.004382	3.411	0.1143
		Developed, Medium Intensity	0	1	0.005825	5.578	0.05615
		Developed, High Intensity	0	1	0.001453	0.820	0.40013
		Barren Land (Rock/ Sand/Clay)	0	1	0.004448	3.492	0.11088
	X	Deciduous Forest	-0.0271405	1	0.446693	258.612	8.74e-7
		Evergreen Forest	0	1	0.004917	4.112	0.08892
		LOG+1Mixed Forest	0	1	0.000232	0.118	0.74343
		Shrub/ Scrub	0	1	0.005066	4.326	0.08274
		LOG+1Grassland/ Herbaceous	0	1	0.004934	4.136	0.0882
		Pasture/ Hay	0	1	0.003448	2.393	0.17281
		Cultivated Crops	0	1	0.000469	0.242	0.64014
	X	Woody Wetlands	0.86018365	1	0.130204	75.381	5.39e-5
		alluvium	0	1	0.004824	3.983	0.09297
		LOG+1alluvium	0	1	0.009084	18.128	0.00533
		alluvium colluvium	0	1	0.005976	5.863	0.05177
		LOG+1alluvium colluvium	0	1	0.008152	12.416	0.01246
		arenite	0	1	0.000976	0.527	0.4952
		arenite conglomerate	0	1	0.000642	0.336	0.58312

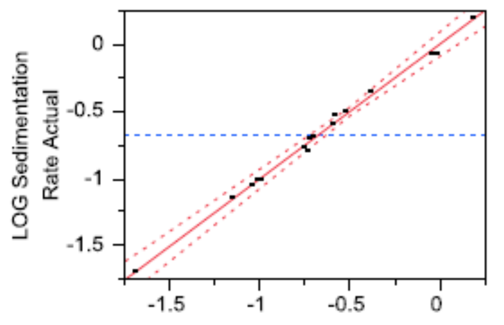
Lock	Entered	Parameter	Estimate	nDF	SS	"F Ratio"	"Prob>F"
		arenite shale	0	1	0.000981	0.530	0.49419
	X	ash-flow tuff basalt	-0.0071638	1	0.060485	35.018	0.00059
		basalt rhyolite	0	1	0.000035	0.017	0.89925
		carbonate sandstone	0	1	0.000642	0.336	0.58312
		clay or mud sand	0	1	0.000642	0.336	0.58312
		conglomerate medium-grained mixed clastic	0	1	0.000642	0.336	0.58312
	X	conglomerate sandstone	0.18371008	1	0.254529	147.359	5.88e-6
		dacite rhyolite	0	1	0.001927	1.137	0.32725
		dolostone (dolomite) arenite	0	1	0.000642	0.336	0.58312
		dolostone (dolomite) sandstone	0	1	0.000053	0.026	0.87621
		dolostone (dolomite) shale	0	1	0.000642	0.336	0.58312
		fine-grained mixed clastic limestone	0	1	0.000644	0.338	0.58231
		fine-grained mixed clastic sandstone	0	1	0.000321	0.163	0.70003
		glacial drift	0	1	0.001599	0.914	0.37591
		limestone	0	1	0.000606	0.316	0.59414
		limestone arenite	0	1	0.000642	0.336	0.58312
		limestone medium-grained mixed clastic	0	1	0.000415	0.213	0.66045
		limestone mudstone	0	1	1.636e-6	0.001	0.97819
		medium-grained mixed clastic sandstone	0	1	0.008142	12.369	0.01256
	X	mudstone conglomerate	-0.0124786	1	0.026823	15.529	0.0056
		mudstone limestone	0	1	0.000365	0.187	0.68058
		mudstone sandstone	0	1	0.000622	0.326	0.58894
	X	mudstone siltstone	-0.231267	1	1.593202	922.383	1.08e-8
		quartz monzonite granite	0	1	7.538e-5	0.038	0.85257
		sandstone	0	1	0.000933	0.502	0.50526
		sandstone conglomerate	0	1	0.005198	4.524	0.07753
		sandstone mudstone	0	1	0.000102	0.051	0.82856
		LOG+1sandstone shale	0	1	8.27e-5	0.041	0.84563
		LOG+1sandstone siltstone	0	1	0.000115	0.058	0.81803
	X	shale limestone	-0.0092155	1	0.010484	6.070	0.04323
		shale sandstone	0	1	0.000053	0.026	0.87627
		shale siltstone	0	1	0.000858	0.458	0.52376
		volcanic rock (aphanitic)	0	1	0.008605	14.810	0.00848
		water	0	1	0.007326	9.225	0.02288

Step History

Step	Parameter	Action	"Sig Prob"	Seq SS	RSquare	Cp	p	AICc	BIC
1	mudstone siltstone	Entered	0.0044	1.499078	0.4512	.	2	18.6582	18.976
2	LOG Surface Area (acres)	Entered	0.0011	1.047244	0.7663	.	3	8.63205	8.08604
3	Deciduous Forest	Entered	0.0057	0.375611	0.8794	.	4	2.4164	0.27934
4	conglomerate sandstone	Entered	0.0416	0.1306	0.9187	.	5	1.44118	-3.2566
5	Woody Wetlands	Entered	0.0127	0.129333	0.9576	.	6	-2.3131	-10.905
6	ash-flow tuff basalt	Entered	0.0067	0.081165	0.9820	.	7	-7.475	-21.866

Step	Parameter	Action	"Sig Prob"	Seq SS	RSquare	Cp	p	AICc	BIC
7	mudstone conglomerate	Entered	0.0067	0.037139	0.9932	.	8	-11.61	-34.657
8	shale limestone	Entered	0.0432	0.010484	0.9964	.	9	-5.6003	-41.874
9	LOG Annual Average Flow (ac-ft/yr)	Entered	0.0034	0.009483	0.9992	.	10	-6.1418	-63.643
10	Hydrologic Number	Entered	0.0020	0.002281	0.9999	.	11	0.62379	-94.105
11	LOG Drainage Area mi^2	Entered	0.0032	0.000297	1.0000	.	12	42.3342	-129.62
12	T Factor	Entered	0.0019	0.000029	1.0000	.	13	224.468	-184.72
13	LOG Max Elevation (m)	Entered	0.0024	7.982e-7	1.0000	.	14	.	-267.11
14	LOG Peak Flow 50 ft^3/s	Entered	0.0007	3.913e-9	1.0000	.	15	-1037.6	-481.23
15	LOG Peak Flow 50 ft^3/s	Removed	0.0007	3.913e-9	1.0000	.	14	.	-267.11
16	LOG Max Elevation (m)	Removed	0.0024	7.982e-7	1.0000	.	13	224.468	-184.72
17	T Factor	Removed	0.0019	0.000029	1.0000	.	12	42.3342	-129.62
18	LOG Drainage Area mi^2	Removed	0.0032	0.000297	0.9999	.	11	0.62379	-94.105
19	Hydrologic Number	Removed	0.0020	0.002281	0.9992	.	10	-6.1418	-63.643
20	LOG Annual Average Flow (ac-ft/yr)	Removed	0.0034	0.009483	0.9964	.	9	-5.6003	-41.874

Response LOG Sedimentation Rate
Actual by Predicted Plot



P<.0001 RSq=1.00

Summary of Fit

RSquare	0.996361
RSquareAdj	0.992203
Root Mean Square Error	0.04156
Mean of Response	-0.67084
Observations (or Sum Wgts)	16

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	8	3.3106538	0.413832	239.5875
Error	7	0.0120909	0.001727	Prob> F
C. Total	15	3.3227447		<.0001*

Parameter Estimates

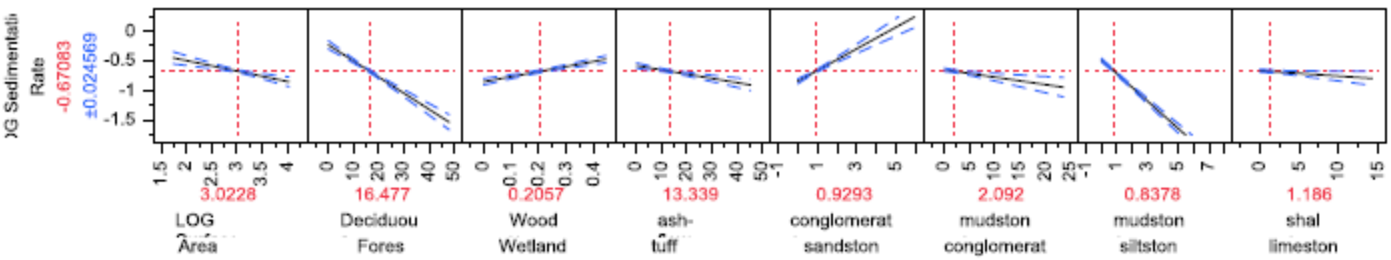
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.2855886	0.071172	4.01	0.0051*
LOG Surface Area (acres)	-0.175511	0.032382	-5.42	0.0010*

Term	Estimate	Std Error	t Ratio	Prob>|t|
Deciduous Forest	-0.02714	0.001688	-16.08	<.0001*
Woody Wetlands	0.8601836	0.099074	8.68	<.0001*
ash-flow tuff basalt	-0.007164	0.001211	-5.92	0.0006*
conglomerate sandstone	0.1837101	0.015134	12.14	<.0001*
mudstone conglomerate	-0.012479	0.003167	-3.94	0.0056*
mudstone siltstone	-0.231267	0.007615	-30.37	<.0001*
shale limestone	-0.009215	0.00374	-2.46	0.0432*

Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	t Ratio	Prob>|t|
mudstone siltstone	-0.231267	0.007615	-30.37		<.0001*
Deciduous Forest	-0.02714	0.001688	-16.08		<.0001*
conglomerate sandstone	0.1837101	0.015134	12.14		<.0001*
Woody Wetlands	0.8601836	0.099074	8.68		<.0001*
ash-flow tuff basalt	-0.007164	0.001211	-5.92		0.0006*
LOG Surface Area (acres)	-0.175511	0.032382	-5.42		0.0010*
mudstone conglomerate	-0.012479	0.003167	-3.94		0.0056*
shale limestone	-0.009215	0.00374	-2.46		0.0432*

Prediction Profiler



Attempt 3

Stepwise Fit for LOG Sedimentation Rate

Stepwise Regression Control

Stopping Rule:

Prob to Enter	0.15
Prob to Leave	0.15
Direction:	

1 rows not used due to excluded rows or missing values.

SSE	DFE	RMSE	RSquare	RSquareAdj	Cp	p	AICc	BIC
0.0406826	8	0.0713115	0.9878	0.9770	.	8	-2.18666	-25.2334

Current Estimates

Lock	Entered	Parameter	Estimate	nDF	SS	"F Ratio"	"Prob>F"
X	X	Intercept	1.74872353	1	0	0.000	1
		Random1	0	1	0.004391	0.847	0.38805
		Random2	0	1	0.000048	0.008	0.93011

Lock	Entered	Parameter	Estimate	nDF	SS	"F Ratio"	"Prob>F"
		Random3	0	1	0.003843	0.730	0.42111
		Random 4	0	1	0.010396	2.403	0.16506
		Date Built	0	1	1.153e-5	0.002	0.96572
	X	LOG Storage Capacity (ac-ft)	-0.0695638	1	0.021517	4.231	0.07371
		LOG Drainage Area mi^2	0	1	0.002829	0.523	0.49296
		Surface Area (acres)	0	1	0.025973	12.360	0.00978
		Annual Average Flow (ac-ft/yr)	0	1	0.019623	6.522	0.03789
		Inflowing Sediment Trapped (%)	0	1	0.007034	1.463	0.26568
		CN Actual	0	1	0.000843	0.148	0.71185
		Hydrologic Number	0	1	1.742e-5	0.003	0.95786
	X	Kw	-6.0258694	1	0.374181	73.581	2.63e-5
		T Factor	0	1	0.000127	0.022	0.88663
		Max Slope (%)	0	1	0.008102	1.741	0.22857
		Mean Slope (%)	0	1	0.001565	0.280	0.613
		LOG Max Elevation (m)	0	1	0.000479	0.083	0.78102
		Average Elevation (m)	0	1	3.078e-8	0.000	0.99823
		January	0	1	0.003664	0.693	0.43265
		February	0	1	0.003189	0.595	0.46557
		March	0	1	0.004936	0.967	0.35827
		April	0	1	0.005987	1.208	0.30811
		May	0	1	0.007999	1.713	0.2319
	X	June	-0.204307	1	0.046622	9.168	0.01636
		July	0	1	0.000128	0.022	0.88601
		August	0	1	0.000232	0.040	0.84702
		September	0	1	0.000238	0.041	0.84481
		October	0	1	0.002035	0.369	0.56292
		November	0	1	0.005021	0.986	0.35388
		December	0	1	0.004409	0.851	0.38698
		Annual	0	1	0.004456	0.861	0.38434
		LOG Open Water	0	1	0.000516	0.090	0.77305
		Developed, Open Space	0	1	0.001232	0.219	0.65429
		Developed, Low Intensity	0	1	8.763e-6	0.002	0.97011
		Developed, Medium Intensity	0	1	0.000175	0.030	0.86703
		Developed, High Intensity	0	1	1.184e-5	0.002	0.96525
	X	Barren Land (Rock/ Sand/Clay)	0.13270332	1	0.305346	60.045	5.49e-5
		Deciduous Forest	0	1	0.005553	1.107	0.32778
		Evergreen Forest	0	1	0.002837	0.525	0.49232
		LOG+1 Mixed Forest	0	1	0.000833	0.146	0.71347
		Shrub/ Scrub	0	1	0.003558	0.671	0.43972
		LOG+1 Grassland/ Herbaceous	0	1	4.819e-5	0.008	0.92995
		Pasture/ Hay	0	1	0.009029	1.997	0.20053
		LOG+1 Cultivated Crops	0	1	0.014018	3.680	0.09657
		Woody Wetlands	0	1	0.008323	1.800	0.22156
		alluvium	0	1	0.002647	0.487	0.50776
		alluvium colluvium	0	1	0.000231	0.040	0.84713
		arenite	0	1	0.00737	1.549	0.25338
		arenite conglomerate	0	1	0.000752	0.132	0.72722
		arenite shale	0	1	0.007875	1.680	0.23598
		ash-flow tuff basalt	0	1	0.000422	0.073	0.79437
		basalt rhyolite	0	1	0.002528	0.464	0.51777
		carbonate sandstone	0	1	0.000752	0.132	0.72722

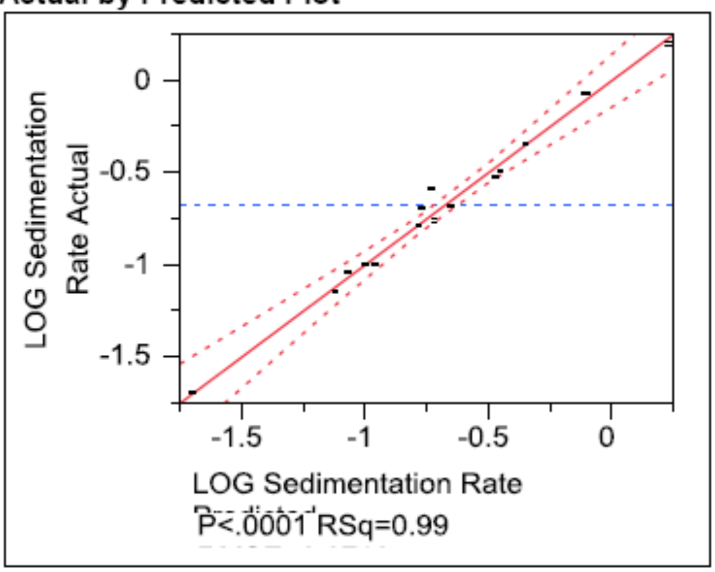
Lock	Entered	Parameter	Estimate	nDF	SS	"F Ratio"	"Prob>F"
		clay or mud sand	0	1	0.000752	0.132	0.72722
		conglomerate medium-grained mixed clastic	0	1	0.000752	0.132	0.72722
		conglomerate sandstone	0	1	0.000273	0.047	0.83409
		dacite rhyolite	0	1	0.000339	0.059	0.81542
		dolostone (dolomite) arenite	0	1	0.000752	0.132	0.72722
		dolostone (dolomite) sandstone	0	1	0.003894	0.741	0.41786
		dolostone (dolomite) shale	0	1	0.000752	0.132	0.72722
	X	fine-grained mixed clastic limestone	-0.0187467	1	0.03482	6.847	0.03081
		fine-grained mixed clastic sandstone	0	1	0.000281	0.049	0.83153
		glacial drift	0	1	0.009747	2.205	0.1811
		limestone	0	1	0.008058	1.729	0.22997
		limestone arenite	0	1	0.000752	0.132	0.72722
		limestone medium-grained mixed clastic	0	1	2.56e-6	0.000	0.98384
		limestone mudstone	0	1	0.008423	1.828	0.21844
		medium-grained mixed clastic sandstone	0	1	0.000184	0.032	0.86356
		mudstone conglomerate	0	1	0.000236	0.041	0.84572
		mudstone limestone	0	1	1.615e-5	0.003	0.95942
		mudstone sandstone	0	1	0.001169	0.207	0.66287
		mudstone siltstone	0	1	0.001486	0.265	0.62232
		quartz monzonite granite	0	1	0.000306	0.053	0.82436
		sandstone	0	1	0.000227	0.039	0.84846
		sandstone conglomerate	0	1	0.001791	0.322	0.58795
		sandstone mudstone	0	1	0.013828	3.604	0.09942
		sandstone shale	0	1	0.009856	2.238	0.1783
		sandstone siltstone	0	1	0.002459	0.450	0.52368
	X	shale limestone	-0.0793005	1	0.544975	107.166	6.55e-6
		shale sandstone	0	1	0.007175	1.499	0.26043
	X	shale siltstone	-0.1286315	1	1.75612	345.331	7.25e-8
		volcanic rock (aphanitic)	0	1	0.002062	0.374	0.56033
		water	0	1	0.001066	0.188	0.67741

Step History

Step	Parameter	Action	"Sig Prob"	Seq SS	RSquare	Cp	p	AICc	BIC
1	mudstone siltstone	Entered	0.0044	1.499078	0.4512	.	2	18.6582	18.976
2	LOG Storage Capacity (ac-ft)	Entered	0.0129	0.709836	0.6648	.	3	14.4059	13.8599
3	Kw	Entered	0.0119	0.470196	0.8063	.	4	9.99462	7.85757
4	shale limestone	Entered	0.0602	0.183457	0.8615	.	5	9.95964	5.26184
5	Barren Land (Rock/ Sand/Clay)	Entered	0.0209	0.197207	0.9209	.	6	7.67317	-0.9187
6	shale siltstone	Entered	0.0309	0.110605	0.9541	.	7	7.51239	-6.8783
7	June	Entered	0.0213	0.076903	0.9773	.	8	7.69848	-15.348
8	mudstone siltstone	Removed	0.9489	4.129e-5	0.9773	.	7	-3.7213	-18.112
9	fine-grained mixed clastic limestone	Entered	0.0308	0.03482	0.9878	.	8	-2.1867	-25.233

Response LOG Sedimentation Rate

Actual by Predicted Plot



Summary of Fit

RSquare	0.987756
RSquare Adj	0.977043
Root Mean Square Error	0.071311
Mean of Response	-0.67084
Observations (or Sum Wgts)	16

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	3.2820621	0.468866	92.1998
Error	8	0.0406826	0.005085	Prob > F

Source	DF	Sum of Squares	Mean Square	F Ratio
C. Total	15	3.3227447		<.0001*

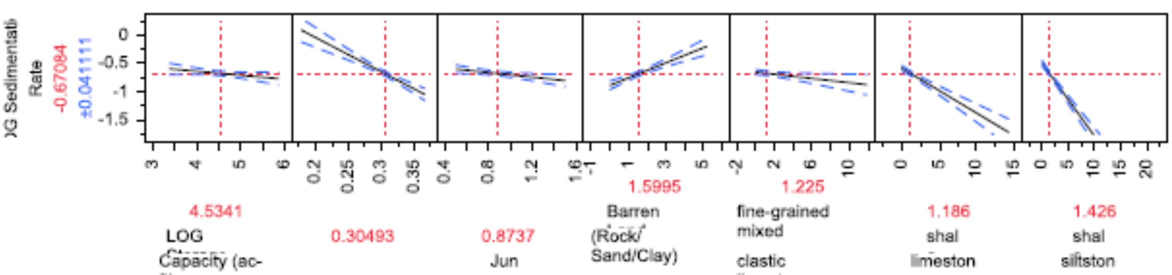
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|	Lower 95%	Upper 95%
Intercept	1.7487235	0.229259	7.63	<.0001*	1.2200522	2.2773949
LOG Storage Capacity (ac-ft)	-0.069564	0.033819	-2.06	0.0737	-0.147549	0.0084219
Kw	-6.025869	0.702487	-8.58	<.0001*	-7.645806	-4.405933
June	-0.204307	0.067476	-3.03	0.0164*	-0.359906	-0.048708
Barren Land (Rock/ Sand/Clay)	0.1327033	0.017126	7.75	<.0001*	0.0932117	0.1721949
fine-grained mixed clastic limestone	-0.018747	0.007164	-2.62	0.0308*	-0.035267	-0.002226
shale limestone	-0.0793	0.00766	-10.35	<.0001*	-0.096965	-0.061636
shale siltstone	-0.128632	0.006922	-18.58	<.0001*	-0.144594	-0.112669

Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	t Ratio	Prob>|t|
shale siltstone	-0.128632	0.006922	-18.58		<.0001*
shale limestone	-0.0793	0.00766	-10.35		<.0001*
Kw	-6.025869	0.702487	-8.58		<.0001*
Barren Land (Rock/ Sand/Clay)	0.1327033	0.017126	7.75		<.0001*
June	-0.204307	0.067476	-3.03		0.0164*
fine-grained mixed clastic limestone	-0.018747	0.007164	-2.62		0.0308*
LOG Storage Capacity (ac-ft)	-0.069564	0.033819	-2.06		0.0737

Prediction Profiler



Variables

						Stream Stats											
	Latitude	Longitude	Date Built	Storage Capacity (ac-ft)	Drainage Area mi^2	Mean Annual Precipitation (in)	Average Basin Slope (%)	Mean Basin Elevation (ft)	Area Covered by Herbaceous Upland (%)	Peak Flow 2 ft^3/s	Peak Flow 5 ft^3/s	Peak Flow 10 ft^3/s	Peak Flow 25 ft^3/s	Peak Flow 50 ft^3/s	Peak Flow 100 ft^3/s	Peak Flow 200 ft^3/s	Peak Flow 500 ft^3/s
Causey	41.30	-111.59	1973	7870.00	80.40	36.4	27.5	7520	22.8	319	432	518	579	692	758	820	919
East Canyon	40.92	-111.60083	1915	31200.00	144.00	26.2	22.5	7090	4.63	231	318	383	441	519	573	626	694
Echo	40.96	-111.42	1930	75718.00	732.00	25	21	7670	7.94	1610	2310	2580	3080	3470	3870	4050	4370
Gunlock	37.26	-113.77	1970	10884.00	306.00	19	19.2	6010	4.6	687	1490	2200	3270	4190	5250	6390	8100
Hyrum	41.62	-111.87	1935	18925.00	220.00	31.7	23.1	6520	18.5	497	826	1010	1300	1530	1770	1950	2210
Lake Powell	36.94	-111.48	1964	27083092.00	26000.00	15.5	14.3	7120	15	28500	41600	54500	64200	74300	94400	96800	113000
Millsite	39.10	-111.19	1971	18000.00	157.00	21.9	22.6	8750	16.1	329	731	1080	1690	2230	3040	3540	4630
Otter Creek	38.18	-112.01	1897	52660.00	364.00	15.4	16.5	7970	4.01	441	830	1130	1550	1970	2300	2730	3370
Piute	38.32	-112.19	1908	81200.00	2440.00	17.1	14.8	8040	5.3	2360	4220	5570	7340	8720	10100	11500	13400
Rocky Ford	38.22	-112.83	1914	23260.00	510.00	18.4	16.3	7340	5.62	374	685	944	1360	1810	2190	2710	3540
Scofield	39.78	-111.15	1946	736000.00	154.00	24	23.4	8610	10.2	346	767	1140	1770	2350	3200	3720	4870
Sevier Bridge	39.37	-112.03	1908	250000.00	5120.00	17.2	16.7	7520	7.98	3230	5170	6460	8130	9720	10700	11900	13700
Starvation	40.19	-110.45	1969	167310.00	950.00	19.1	20.4	7820	7.08	1950	3450	5570	6140	7270	8880	10200	12200
Steinaker	40.52	-109.53	1961	40335.00	19.00	10.2	13.7	6030	4.33	31.7	69.4	119	156	201	260	319	418
Upper Enterprise	37.52	-113.86	1909	9000.00	25.00	25.8	17.2	6310	2.92	42.1	121	214	389	573	802	1090	1580
Wanship	40.79	-111.41	1957	62116.00	320.00	28.6	24.4	8160	4.84	1120	1620	1830	2200	2510	2810	2980	3250
Wide Hollow	37.79	-111.64	1954	2324.00	10.00	10.8	14.9	6480	8.65	153	415	682	1180	1660	2290	2910	4040
Yankee Meadows	37.75	-112.77	1926	2500.00	7.00	27.8	20.2	9340	0.82	17.7	65.2	130	271	435	668	990	1590

	Bureau of Reclamation/ Division of Water Rights														
	Dam Type	Structural Height (ft)	Hydraulic Height (Normal Operating Depth at Dam) (ft)	Spillway Type	Spillway Crest Elevation	Crest Elevation (ft)	Streambed at Dam Axis (ft)	Top of Joint Use Pool (Elevation) (ft)	Top of Active Conservation Pool (Elevation) (ft)	Top of Inactive Conservation Pool (Elevation) (ft)	Top of Dead Storage Pool (Elevation) (ft)	Maximum Water Surface Elevation (ft)	Spillway Capacity (cfs)	Outlet Works Capacity at Elevation (cfs)	Surface Area (acres)
Causey	Earth fill	217.50	193.10		5692.00	5704.00	5505	5692			5601	5698	7570	8900	136
East Canyon	Concrete thin-arch	259.80	195.00			5715.00	5520	5705		5577	5565	5715	6200	700	684
Echo	Earth fill	158.00	110.00		5543.00	5570.00	5450		5560		5450	5560	15000	2100	480
Gunlock	Earth fill		103.00	Open Channel		3597.00							42400	140	266
Hyrum	Rolled Earth and Rock fill	116.00	82.00			4680.00	4590		4672	4634	4630	4672	6000	300	480
Lake Powell	Concrete Arch	710.00	579.00			3715.00	3132			3490	3370	3711	208000	15000	161390
Millsite			107.00	Drop Inlet		6225.00							5450	480	435
Otter Creek			38.00	Open Channel		6381.00							2500	670	2520
Piute	rolled earth fill and hydraulic fill	90.00													2815
Rocky Ford	Earth fill														990
Scofield	Earth fill	96.00	60.00			7636.00	7570		7617		7586	7630	6200	500	2815
Sevier Bridge															10905
Starvation	Earth fill	200.30	162.00			5725.00	5563	5712		5625	5595	5718	16000	2310	2760
Steinaker	Earth fill	162.20	131.50			5527.00	5389		5518	5446	5446	5527			820
Upper Enterprise	Earth fill														265
Wanship	Earth fill	175.00	150.00			6088.00	5899				5930	6049	10800	1000	1189
Wide Hollow															145
Yankee Meadows															53

	USGS Surface-Water			Soil			GIS				
	Annual Average Flow (ac-ft/yr)	Inflowing Sediment Trapped (%)	CN	Hydrologic Number	Kw	T Factor	Max Slope (%)	Mean Slope (%)	Stream Order	Max Elevation (m)	Average Elevation (m)
Causey	46483.1	91	75	2.00	0.32	4.00	67.19	19.10	3	2783	2291
East Canyon	38545.4	97	73	3.00	0.32	3.00	58.02	15.10	3	9071	2146
Echo	211823.1	95	72	3.00	0.32	3.00	68.27	13.79	4	3636	2345
Gunlock	17814.5	96.25	70	4.00	0.24	1.00	66.62	14.03	4	3161	1836
Hyrum	59898.3	94	72	3.00	0.37	3.00	63.20	15.70	4	2868	2002
Lake Powell				3.00	0.26	3.00	89.83	8.89	7	4393	2150
Millsite	47375.4	95.5	79	3.00	0.35	2.00	66.90	13.97	4	3400	2692
Otter Creek	7231.2	98.5	55	2.00	0.33	3.00	68.66	10.79	4	3543	2433
Piute	171918.0	95.75	70	3.00	0.32	3.00	73.45	10.30	5	3543	2452
Rocky Ford	5520.0	98	56	2.00	0.31	3.00	65.20	11.20	4	3704	2240
Scofield	93148.4	99	80	3.00	0.31	3.00	51.24	15.30	3	3183	2624
Sevier Bridge	346966.0	96.5	71	3.00	0.32	3.00	75.22	11.38	5	3705	2291
Starvation	138023.3	97.5	72	3.00	0.29	3.00	67.80	14.30	5	3226	2390
Steinaker	25237.4	97.75	79	4.00	0.18	1.00	57.25	10.37	2	2366	1835
Upper Enterprise	12223.7	96.75	81	4.00	0.36	2.00	48.43	13.40	2	2286	1923
Wanship	123865.0	96	73	3.00	0.31	3.00	72.67	15.37	4	3632	2497
Wide Hollow	237.0	99	70	3.00	0.27	2.00	49.50	9.99	2	2349	1975
Yankee Meadows	2849.0	97.25	73	3.00	0.29	4.00	58.50	12.97	1	3224	2889

	Precipitation												
	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Causey	3.96	3.25	3.64	3.28	3.02	1.50	1.05	1.50	2.49	2.50	3.42	3.65	32.83
East Canyon	2.95	2.78	3.11	2.65	2.54	1.50	1.24	1.41	1.67	2.54	2.90	2.33	27.05
Echo	2.58	2.46	2.75	2.78	2.61	1.47	1.38	1.37	1.75	2.11	2.59	2.18	25.90
Gunlock	1.96	2.43	2.76	1.41	1.11	0.50	0.94	1.62	1.32	1.65	1.62	1.46	18.89
Hyrum	3.63	3.28	3.39	2.91	2.96	1.50	1.27	1.47	2.09	2.54	3.06	3.24	31.30
Lake Powell	1.25	1.15	1.44	1.30	1.39	0.81	1.26	1.32	1.29	1.52	1.24	1.09	15.61
Millsite	2.56	2.45	2.75	2.01	2.02	0.97	1.50	1.86	1.89	2.06	2.40	2.04	24.33
Otter Creek	1.42	1.36	1.98	1.53	1.36	0.60	1.35	1.62	1.41	1.52	1.40	1.20	17.22
Piute	1.63	1.70	2.08	1.33	1.26	0.56	1.48	1.89	1.49	1.77	1.50	1.20	18.31
Rocky Ford	1.64	1.59	2.30	1.90	1.77	0.72	1.51	1.81	1.63	1.71	1.46	1.31	19.25
Scofield	2.51	2.47	2.67	2.12	1.80	1.03	1.42	1.50	1.81	2.27	2.20	2.02	23.75
Sevier Bridge	1.59	1.61	2.07	1.51	1.48	0.65	1.27	1.58	1.42	1.75	1.56	1.26	18.06
Starvation	2.11	1.89	2.03	1.59	1.54	0.98	1.42	1.84	1.73	1.87	2.12	1.67	20.79
Steinaker	0.50	0.54	0.67	1.00	1.50	0.56	0.60	0.55	1.39	1.50	0.51	0.50	10.77
Upper Enterprise	2.97	3.90	3.50	1.50	1.50	0.50	1.27	1.50	1.50	2.22	2.34	2.43	24.49
Wanship	3.10	2.95	3.27	3.25	2.77	1.43	1.49	1.53	1.92	2.30	3.01	2.63	29.77
Wide Hollow	0.90	0.72	1.21	0.50	0.50	0.50	0.84	1.50	1.50	1.50	0.50	0.50	11.39
Yankee Meadows	3.29	3.48	4.29	2.50	1.50	0.50	1.68	2.50	2.20	2.50	2.50	2.50	30.47

	Land use														
	Open Water	Perennial Ice/Snow	Developed, Open Space	Developed, Low Intensity	Developed, Medium Intensity	Developed, High Intensity	Barren Land (Rock/ Sand/Clay)	Deciduous Forest	Evergreen Forest	Mixed Forest	Shrub/ Scrub	Grassland / Herbaceous	Pasture/ Hay	Cultivated Crops	Woody Wetlands
Causey	0.19	0.00	0.16	0.00	0.00	0.00	0.01	67.20	16.42	1.02	14.93	0.02	0.03	0.00	0.00
East Canyon	0.65	0.00	2.91	0.99	0.66	0.05	0.04	48.14	13.74	0.52	30.53	0.01	1.09	0.41	0.26
Echo	0.60	0.00	1.45	0.26	0.14	0.01	1.15	37.06	22.45	1.25	30.42	0.55	3.76	0.42	0.18
Gunlock	0.08	0.00	0.50	0.02	0.00	0.00	0.02	0.54	56.01	0.83	39.35	0.94	1.29	0.02	0.39
Hyrum	0.38	0.00	1.28	0.32	0.01	0.00	0.01	40.22	13.68	0.84	34.37	0.24	5.47	2.72	0.44
Lake Powell	0.56	0.15	0.54	0.24	0.06	0.01	5.24	7.01	20.88	0.72	51.75	9.19	2.14	0.51	0.75
Millsite	0.39	0.00	1.04	0.05	0.00	0.00	3.84	11.75	34.89	6.70	35.35	5.80	0.06	0.00	0.14
Otter Creek	0.77	0.00	1.10	0.83	0.10	0.00	0.17	8.06	32.62	4.02	49.88	0.50	1.18	0.62	0.15
Piute	0.35	0.00	1.28	0.53	0.19	0.01	1.60	3.17	47.18	3.96	39.38	0.71	1.19	0.33	0.12
Rocky Ford	0.17	0.00	1.54	0.64	0.37	0.01	0.56	4.09	46.05	4.74	36.96	1.35	3.22	0.24	0.05
Scofield	2.66	0.00	1.12	0.08	0.00	0.00	0.14	42.86	19.04	2.52	31.15	0.39	0.00	0.00	0.03
Sevier Bridge	0.51	0.00	1.66	0.58	0.18	0.01	1.38	7.27	41.58	3.08	38.00	0.94	3.28	1.26	0.27
Starvation	2.60	0.00	0.86	0.08	0.00	0.00	4.13	24.04	29.20	1.39	36.73	0.11	0.71	0.02	0.13
Steinaker	4.24	0.00	0.84	1.36	0.06	0.00	5.19	0.06	29.63	0.01	54.56	0.18	3.45	0.00	0.42
Upper Enterprise	1.17	0.00	0.00	0.00	0.00	0.00	0.01	5.45	75.33	0.00	17.84	0.02	0.03	0.00	0.14
Wanship	0.67	0.00	1.17	0.17	0.05	0.00	2.27	30.72	36.06	1.38	20.32	0.72	5.38	0.82	0.25
Wide Hollow	1.58	0.00	0.00	0.00	0.00	0.00	3.23	0.00	42.44	0.00	50.77	0.76	0.89	0.00	0.32
Yankee Meadows	5.33	0.00	0.76	0.05	0.00	0.00	1.85	0.21	47.40	41.90	2.51	0.00	0.00	0.00	0.00

	Geology														
	alluvium	alluvium colluvium	arenite	arenite conglomerate	arenite shale	ash-flow tuff basalt	basalt rhyolite	carbonate sandstone	clay or mud sand	conglomerate medium-grained mixed clastic	conglomerate sandstone	dacite rhyolite	dolostone (dolomite) arenite	dolostone (dolomite) sandstone	dolostone (dolomite) shale
Causey	1.45	0.02	0.00	3.68	0.00	0.00	0.00	2.02	0.00	58.49	0.16	0.00	4.40	6.78	4.92
East Canyon	0.00	11.95	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.92	18.72	0.00	0.00	0.00
Echo	0.67	11.18	2.50	0.00	5.27	0.00	0.00	0.00	0.00	0.00	2.14	7.77	0.00	1.52	0.00
Gunlock	2.95	7.01	0.00	0.00	0.00	31.53	16.68	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00
Hyrum	0.00	5.01	0.00	7.06	0.00	0.00	0.00	9.21	6.20	10.93	0.00	0.00	6.13	6.43	9.03
Lake Powell	2.22	3.62	0.11	0.00	0.84	0.47	0.10	0.00	0.00	0.05	0.58	0.09	0.00	0.05	0.00
Millsite	0.33	0.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Otter Creek	22.79	3.54	0.00	0.00	0.00	42.07	2.04	0.00	0.00	0.00	0.00	22.59	0.00	0.00	0.00
Piute	6.06	16.83	0.00	0.00	0.00	31.01	5.72	0.00	0.00	0.00	0.00	9.97	0.00	0.00	0.00
Rocky Ford	11.37	26.86	0.00	0.00	0.00	39.26	0.84	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00
Scofield	0.00	1.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.69	0.00	0.00	0.00	0.00
Sevier Bridge	3.89	22.85	0.00	0.00	0.00	24.06	2.71	0.00	0.00	0.00	0.00	6.91	0.00	0.00	0.00
Starvation	3.56	2.59	0.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
Steinaker	0.00	3.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Upper Enterprise	0.00	0.00	0.00	0.00	0.00	45.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wanship	1.06	14.79	5.44	0.00	11.46	0.00	0.00	0.00	0.00	0.00	3.12	12.15	0.00	3.30	0.00
Wide Hollow	3.67	36.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Yankee Meadows	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

	Geology													
	fine-grained mixed clastic limestone	fine-grained mixed clastic sandstone	glacial drift	limestone	limestone arenite	limestone medium-grained mixed clastic	limestone mudstone	medium-grained mixed clastic sandstone	mudstone conglomerate	mudstone limestone	mudstone sandstone	mudstone siltstone	quartz monzonite granite	sandstone
Causey	0.00	0.00	0.00	6.72	3.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
East Canyon	0.00	0.00	3.35	0.00	0.00	0.00	1.31	0.00	23.70	5.00	0.00	2.16	0.00	5.78
Echo	11.87	0.00	8.58	1.25	0.00	0.00	0.18	0.00	8.37	0.21	1.03	0.88	0.00	0.44
Gunlock	0.00	0.00	0.00	0.00	0.00	0.00	5.24	7.00	0.00	0.00	0.00	0.00	13.71	0.00
Hyrum	0.00	0.00	0.33	1.83	7.14	0.00	0.00	0.00	0.00	0.00	19.98	0.00	0.00	0.00
Lake Powell	1.01	0.28	2.24	0.10	0.00	0.09	0.05	0.00	0.27	0.02	7.09	0.10	0.00	3.36
Millsite	0.00	43.24	9.25	0.00	0.00	20.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Otter Creek	0.00	0.00	0.20	0.01	0.00	0.00	0.32	0.00	0.00	0.00	0.00	0.00	0.02	0.00
Piute	0.00	0.00	0.03	0.00	0.00	0.00	17.31	0.58	0.00	0.00	0.00	0.00	0.01	0.00
Rocky Ford	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.71	0.00
Scofield	0.49	18.94	0.00	0.00	0.00	6.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sevier Bridge	0.00	5.79	1.11	0.00	0.00	3.34	12.94	0.27	0.00	0.00	1.02	0.00	0.15	0.00
Starvation	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.68	0.00	0.09
Steinaker	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.92	0.00	40.17
Upper Enterprise	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.76	0.00	0.00	0.00	0.00	0.00	0.00
Wanship	7.25	0.00	17.89	2.72	0.00	0.00	0.00	0.00	1.40	0.00	0.00	1.76	0.00	0.78
Wide Hollow	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Yankee Meadows	0.00	0.00	0.00	0.00	0.00	0.00	8.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00

	Geology								
	sandstone conglomerate	sandstone mudstone	sandstone shale	sandstone siltstone	shale limestone	shale sandstone	shale siltstone	volcanic rock (aphanitic)	water
Causey	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.49
East Canyon	0.00	2.88	12.50	0.00	0.00	0.00	1.36	0.00	0.37
Echo	0.00	11.82	15.42	0.00	0.55	0.00	0.37	0.00	0.47
Gunlock	0.00	7.84	0.22	5.04	0.00	0.00	0.00	1.79	0.06
Hyrum	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.76
Lake Powell	1.45	10.33	10.84	4.95	2.52	8.24	0.06	0.00	0.46
Millsite	0.00	0.00	0.00	0.00	0.00	25.73	0.00	0.00	0.00
Otter Creek	0.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
Piute	0.68	1.21	0.00	0.00	0.00	0.00	0.00	6.53	0.47
Rocky Ford	6.92	0.00	0.00	0.46	0.00	0.00	0.00	0.91	0.41
Scofield	0.00	0.00	33.23	0.00	0.00	32.72	0.00	0.00	2.97
Sevier Bridge	1.11	2.39	0.00	0.13	2.94	1.73	0.00	3.08	0.40
Starvation	0.00	65.92	4.15	0.00	14.27	2.11	0.00	0.00	3.10
Steinaker	0.00	10.30	1.09	0.00	0.00	8.00	20.41	0.00	8.92
Upper Enterprise	0.00	0.00	0.00	0.00	0.00	0.00	0.00	42.04	1.71
Wanship	0.00	0.12	6.20	0.00	1.21	0.00	0.68	0.00	0.53
Wide Hollow	0.00	38.10	6.44	0.00	0.00	15.21	0.00	0.00	0.57
Yankee Meadows	0.00	0.00	0.00	0.00	0.00	0.00	0.00	87.32	3.96

Information Transfer Program Introduction

The individual research projects documented in the Research Project section of this report have information and outreach components integrated within them. These include research findings published in the technical literature and findings and water management models and tools provided on the web pages of the Utah Center for Water Resources Research (UCWRR) and individual water agencies. Beyond this, Information Transfer and Outreach activities through the UCWRR, the Utah Water Research Laboratory (UWRL), and Utah State University (USU) have had an impact on the technical and economic development of the State of Utah. As part of the UCWRR outreach activities supported by USGS 104 funds, there continues to be a vigorous dialogue and experimentation with regard to the efficiency and effectiveness of outreach activities of the UCWRR. Faculty are engaged in regular meetings with State of Utah water resources agencies, including the Department of Environmental Quality (DEQ), the Department of Natural Resources (DNR), the State Engineer's Office, and numerous municipal water supply and irrigation companies to provide assistance in source water protection, on-site training, non-point source pollution management, technology transfer, development of source water protection plans (SWPPs), and efficient management of large water systems within the context of water-related issues in Utah. UCWRR staff, through the facilities at the UWRL, provides short courses both on- and off-site within the State of Utah, regionally, and internationally. Generally offered from one to five days in duration, short courses are tailored to meet the needs of the requestor. The following is a partial list of short courses, field training, and involvement of UCWRR staff in information transfer and outreach activities.

Principal Outreach Publications

Principal outreach items include our two newsletters, “The Water bLog” (http://uwrl.usu.edu/partnerships/ucwrr/newsletter/index.html), which highlights research projects and their findings, and “The Utah WaTCH” (http://uwrl.usu.edu/partnerships/training/utahwatch.html), which addresses on-site and wastewater issues; and reports such as the Mineral Lease Report (http://uwrl.usu.edu/documents/index.html), which is submitted to the Utah Office of the Legislative Fiscal Analyst. Other publications from the UCWRR and UWRL appear regularly as technically-reviewed project reports, professional journal articles, other publications and presentations, theses and dissertation papers presented at conferences and meetings, and project completion reports to other funding agencies.

Short Courses

US Army Corps of Engineers, Utah Water Research Laboratory. International Workshop on “Exploration of Tolerable Risk Guidelines for Levee Systems.” Alexandria, Virginia, March 17-18, 2010, D.S. Bowles.

US Society on Dams, Utah Water Research Laboratory. “USSD Workshop on Case Histories in Dam Safety Assessment.” Sacramento, CA, April 15, 2010. D.S. Bowles.

Utah On-Site Wastewater Treatment Training Program. “Level 3: Renewal of Certification: Design, Operation, and Maintenance on Alternative Wastewater Treatment Systems,” April 22, 2010, N. Logan, Utah. Judith L. Sims and Brian Cowan.

Utah On-Site Wastewater Treatment Training Program. “Level 1: Certification: Soil Evaluation and Percolation Testing,” May 11-12, 2010, Ogden, Utah. Judith L. Sims, Peg Cashell, and Brian Cowan.

Utah On-Site Wastewater Treatment Training Program. “Level 1: Renewal of Certification: Soil Evaluation and Percolation Testing,” May 13, 2010, Ogden, Utah. Judith L. Sims, Peg Cashell, and Brian Cowan.

Utah On-Site Wastewater Treatment Training Program. “Level 2: Renewal of Certification: Design, Operation, and Maintenance on Conventional On-Site Wastewater Systems,” May 14, 2010, Ogden, Utah. Judith L. Sims, Brian Cowan.

Utah Water Research Laboratory, Utah State University. “Instream Flow Habitat Modeling—Physical Habitat Modeling (PHABSIM).” Logan, Utah, May 17-21, 2010. Thomas B. Hardy.

Utah On-Site Wastewater Treatment Training Program. “Level 1: Certification: Soil Evaluation and Percolation Testing,” September 20-21, 2010, Heber City, Utah. Judith L. Sims, Peg Cashell, and Brian Cowan.

Utah On-Site Wastewater Treatment Training Program. “Level 1: Renewal of Certification: Soil Evaluation and Percolation Testing,” September 22, 2010, Heber City, Utah. Judith L. Sims, Peg Cashell, and Brian Cowan.

Utah On-Site Wastewater Treatment Training Program. “Level 2: Renewal of Certification: Design, Operation, and Maintenance on Conventional On-Site Wastewater Systems,” September 23, 2010, Heber City, Utah. Judith L. Sims, Brian Cowan.

Utah On-Site Wastewater Treatment Training Program. “Level 3: Renewal of Certification: Design, Operation, and Maintenance on Alternative Wastewater Treatment Systems,” September 29, 2010, N. Logan, Utah. Judith L. Sims and Brian Cowan.

Utah On-Site Wastewater Treatment Training Program. “Level 1: Renewal of Certification: Soil Evaluation and Percolation Testing,” October 13, 2010, North Logan, Utah. Judith L. Sims, Peg Cashell, and Brian Cowan.

Utah On-Site Wastewater Treatment Training Program. “Level 2: Renewal of Certification: Design, Operation, and Maintenance on Conventional On-Site Wastewater Systems,” October 14, 2010, North Logan, Utah. Judith L. Sims, Brian Cowan.

Utah On-Site Wastewater Treatment Training Program. “Level 2: Certification: Design, Operation, and Maintenance on Conventional On-Site Wastewater Treatment Systems,” May 26-27, 2010, N. Logan, Utah. Judith L. Sims, Brian Cowan.

Utah On-Site Wastewater Treatment Training Program. “Level 2: Certification: Design, Operation, and Maintenance on Conventional On-Site Wastewater Treatment Systems,” October 19-20, 2010, N. Logan, Utah. Judith L. Sims, Brian Cowan.

Utah On-Site Wastewater Treatment Training Program. “Level 3: Certification: Design, Operation, and Maintenance on Alternative On-site Wastewater Treatment Systems,” June 1-3, 2010, N. Logan, Utah. Judith L. Sims, Brian Cowan, Richard Jex.

Utah On-Site Wastewater Treatment Training Program. “Level 3: Certification: Design, Operation, and Maintenance on Alternative On-site Wastewater Treatment Systems,” October 26-28, 2010, N. Logan, Utah. Judith L. Sims, Brian Cowan, Richard Jex.

Information Transfer in Support of the Utah Center for Water Resources Research (UCWRR)

Basic Information

Title:	Information Transfer in Support of the Utah Center for Water Resources Research (UCWRR)
Project Number:	2010UT136B
Start Date:	3/1/2010
End Date:	2/28/2011
Funding Source:	104B
Congressional District:	UT 1
Research Category:	Not Applicable
Focus Category:	Education, None, None
Descriptors:	None
Principal Investigators:	R. Ivonne Harris

Publications

There are no publications.

Information Transfer in Support of the Utah Center for

Water Resources Research (UCWRR)

Problem

The Water Resources Research Act of 1964 established the Utah Center for Water Resources Research (UCWRR). The Center is housed at Utah State University in Logan, Utah. The general purposes of the UCWRR are to foster interdepartmental research and educational programs in water resources; administer the State Water Research Institute Program funded through the U.S. Geological Survey at Utah State University for the State of Utah; and provide university-wide coordination of water resources research.

Objectives

The center plays a vital role in the dissemination of information. Utah is home to approximately 50,000 miles of rivers and streams and 7,800 lakes. This water is an essential resource for the economic, social, and cultural well being of the State of Utah. As one of 54 water research centers, the UCWRR works to "*make sure that tomorrow has enough clean water.*"

A major component of the information transfer and outreach requirements of the UCWRR is the development of appropriate vehicles for dissemination of information produced by research projects conducted at the Center. This project provides on-going updates of the UCWRR web page, with information transfer specifically identified as the key objective. This project is in the process of disseminating quarterly newsletters for the Utah Center that feature research projects and their findings, water-related activities in the state, and on-going work by researchers affiliated with the Center.

Methods

Web Page

A vital objective in the dissemination of information for the UCWRR was the development of an up-to-date web page. The UCWRR web pages have been developed to make information available and thus creating a tool wherein interested parties can find solutions to water problems. The design of the web pages is developed with Adobe “Dreamweaver” software and CSS. Pictures are taken from the various on-going projects and added to the web pages. The address for the UCWRR is http://uwrl.usu.edu/partnerships/ucwrr/. Figures 1 and 2 are pictures of two of the pages. The web pages are a work-in-progress and the pages are periodically updated.

1. The “Homepage” explains the center’s purpose.

2. The “About Us” gives an overview of the center and its affiliations.

3. The “People” page gives an overview of the governing body of the center as well as key contact staff.

4. The “Research and Publications” page guides you to the various projects and reports. This page is updated periodically.

5. The “Contact” page has the center’s address and mode of contact.

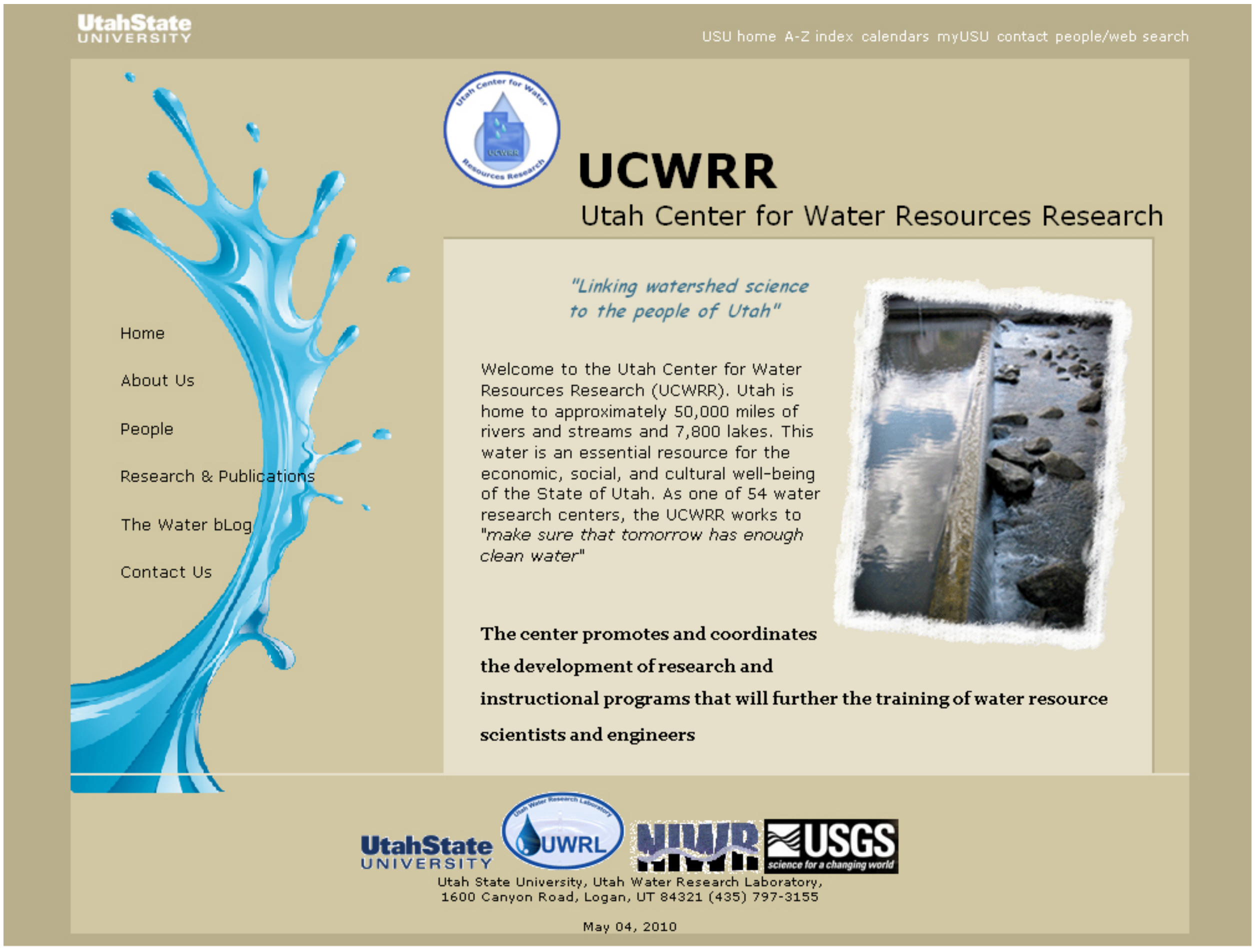


Figure 1. Home page for the UCWRR.

Figure 2. Research and Publications page for the UCWRR.

Newsletter

A semi-annual newsletter *The Water bLog* has been published. *"The Water blog"* is disseminated electronically as well as through e-mail. The newsletter is sent to approximately 350 readers through e-mail. The main purpose of the newsletter is to highlight research projects and their findings. These will be of great interest and value to the State of Utah, also nationally and internationally. Figure 3 shows the first page of *The Water blog's* May 2011 issue. For an electronic copy please go to <http://uwrl.usu.edu/partnerships/ucwrr/newsletter/>.

May 2011, Vol. 2, No. 1

The Water bLog

a newsletter of the

Utah Center for Water Resources Research

at Utah State University

Welcome!

The Water bLog is the semi-annual newsletter of the Utah Center for Water Resources Research (UCWRR), housed at the Utah Water Research Laboratory. The center supports the development of applied research related to water resources problems in Utah and promotes instructional programs that will further the training of water resource scientists and engineers. Each issue of *The Water bLog* highlights a small selection of research from the many projects currently underway at the center. More information is available online at:

http://uwrl.usu.edu/partnerships/ucwrr/

INSIDE:

Research Highlight:

"Biological Processes for the Removal of Phosphorus from Lagoon Wastewater Facilities"

"Cooperative Study of Ambient Ammonia Distribution and Vertical Ozone Profiles"

Update:
Nutrients and Water Quality: A Region 8 Collaborative Workshop

Far Afield:
Projects and Visitors

UtahStateUniversity

Message from the Director

Mac McKee, Director

We are always proud of the tremendous research performed here at the UCWRR, but it is particularly gratifying when recognition comes from other sources. The UCWRR at Utah State University is one of 54 water institutes and centers across the country that receive matching grants under section 104 of the Water Resources Research Act of 1984. The Act requires a periodic review of each institute/center to determine its continued eligibility under the Act. Our latest review identified the UCWRR as "an exemplary program in virtually all respects" and "of among the very best of the 54 institutes nationwide." None of this could be accomplished without the hard work and dedication of our exceptional faculty, researchers, staff, and students. Well done!

This edition of *The Water bLog* features research projects that are developing biological processes for the removal of nutrients from wastewater, including phosphorus and nitrogen, and examining the vertical ozone structure in the wintertime air in the Cache Valley and other locations in Utah. These projects, of course, are directed at serious natural resources problems in the state and are the products of partnerships with state and local resources management and regulatory agencies and stake-holders. ■

RESEARCH HIGHLIGHT

Biological Processes for the Removal of Phosphorus from Lagoon Wastewater Facilities

Recent research at the UCWRR is evaluating the use of indigenous duckweed to remove excess phosphorus and nitrogen, as well as personal care products and pharmaceuticals, from lagoon wastewater treatment facilities.

A variety of ongoing research projects at the Utah Center for Water Resources Research (UCWRR) at Utah State University are directed at developing and evaluating biological processes to remove nutrients from lagoon wastewater treatment systems. One of these efforts is a study to evaluate the effectiveness of duckweed (*Lemna minor*) as a biological technology for managing nutrients (particularly nitrogen and phosphorus)

Partial early spring duckweed coverage on the 56 acre Wellsville lagoons

The Water bLog May 2010, Vol. 2, No. 1

Figure 3. *The Water bLog*, the Newsletter for the UCWRR.

Data Base

Another concern the UCWRR has is making available electronic copies of research projects and reports. These are being converted to PDF format and have been added to a database to make them available on-line. This is a work in progress and some of the publications can be found in our website at http://uwrl.usu.edu/publications.

USGS Summer Intern Program

None.

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	2	0	0	0	2
Masters	3	0	0	1	4
Ph.D.	1	0	0	2	3
Post-Doc.	1	0	0	0	1
Total	7	0	0	3	10

Notable Awards and Achievements

UCWRR faculty member Dr. Laurie McNeill, Associate Professor of Civil and Environmental Engineering at Utah State University was named “Utah Professor of the Year” for 2010 by the Carnegie Foundation for the Advancement of Teaching, an award that recognizes and celebrates “extraordinary dedication to undergraduate teaching.”

Utah State University graduate students Ruba Mohamed, Morris Demitry, and Adel Abdallah were awarded Ivanhoe Foundation fellowships for their water-related research. The foundation grants fellowships to deserving graduate students from developing countries studying at US universities who are pursuing degrees in engineering or science with an emphasis on water resources.

The Utah Center for Water Resources Research and the Utah Water Research Laboratory were pleased to participate with the Colorado Water Institute, the Northern Plains and Mountains Regional Water Program, and the US Environmental Protection Agency in co-hosting “Nutrients and Water Quality: A Region 8 Collaborative Workshop” held in Salt Lake City, Utah February 15-17, 2011. The workshop brought together water management agencies, universities, and various stakeholders from the six states of EPA Region 8 (Colorado, Montana, North Dakota, South Dakota, Utah, and Wyoming to better understand the challenges associated with developing and implementing nutrient controls and management while preserving other important stakeholder values. The three-day workshop provided an opportunity to build a better informed and more tightly linked community of nutrient researchers, regulators, managers, policy makers and stakeholders to promote collaborative approaches to nutrient controls and management.

Publications from Prior Years

1. 2007UT87B ("Two-Zone Temperature and Solute Model Testing and Development in the Virgin River") - Articles in Refereed Scientific Journals - Bandaragoda, C. and B.T. Neilson (2010). "Increasing Parameter Certainty and Data Utility Through Multi-Objective Calibration of a Spatially Distributed Temperature and Solute Model." Hydrology and Earth System Sciences Discussion, 7:8309-8345, 2010 (www.hydrol-earth-syst-sci-discuss.net/7/8309/2010/) doi:10.5194/hessd-7-8309-2010. (IF = 2.167).
2. 2007UT87B ("Two-Zone Temperature and Solute Model Testing and Development in the Virgin River") - Articles in Refereed Scientific Journals - Bandaragoda, C. and B.T. Neilson (2011). "Increasing Parameter Certainty and Data Utility Through Multi-Objective Calibration of a Spatially Distributed Temperature and Solute Model." Hydrology and Earth System Sciences, 15:1547-1561, doi:10.5194/hess-15-1547-2011. (IF = 2.167)
3. 2007UT87B ("Two-Zone Temperature and Solute Model Testing and Development in the Virgin River") - Articles in Refereed Scientific Journals - Bingham, Q.G., B.T. Neilson, C.M.U. Neale, M.B. Cardenas (In review). "Delineation of Dead Zones in Rivers Using Remotely-Sensed Data and Their Utility in Improving Two-Zone Temperature and Solute Transport Model Performance." Water Resources Research. In review. (IF = 2.447)
4. 2008UT106B ("Basin-Scale Internal Waves Within the South Arm of the Great Salt Lake") - Articles in Refereed Scientific Journals - Spall, R.E. (2009). "A Hydrodynamic Model of the Circulation Within the South Arm of the Great Salt Lake." International Journal of Modeling and Simulation, 29:181-190.
5. 2007UT80B ("Development and Calibration of a Hydrodynamic Model for Utah Lake") - Conference Proceedings - Spall, R.E., B. Wilson, and E. Callister, E. (2009). "A Time-Dependent, Three-Dimensional Circulation Model of Utah Lake." HT-2009-88350. Proceedings of the Heat Transfer Division Summer Conference, San Francisco, CA, July 19-23, 2009.
6. 2009UT125B ("Drought Planning Including Carryover Surface Water Storage for a Utah Water Service Provider") - Conference Proceedings - Tesfatsion, Bereket and David E. Rosenberg. (2011) "Managing Water Shortages in the Weber Basin using WEAP." Utah Section of the American Water Resources Association (AWRA), 39th Annual Water Resources Conference “Water Conservation: The Keystone of Sustainable Water Management." Salt Lake City, Utah, May 10, 2011.
7. 2006UT72B ("Potential Impacts of Flow Augmentation on Stream Restoration Projects") - Articles in Refereed Scientific Journals - Rader, Russell B., Mark C. Belk, Rollin Hotchkiss, and Jaron Brown (2010). The Stream-Lake Ecotone: Juvenile Habitat for Endangered June Suckers (Chasmistes liorus). Western North American Naturalist, 70(4):533-561.
8. 2006UT72B ("Potential Impacts of Flow Augmentation on Stream Restoration Projects") - Conference Proceedings - Brown, Jaron M., Rollin H. Hotchkiss, Aaron E. Beavers, Mark W.L. Morris, Shawn M. Stanley, Joseph R. Webb, John R. Aedo, and Tammy B. Thompson (2007). "Bedload Transport in a Supply-Limited Gravel Bed Stream." Proceedings, Hydraulic Measurements and Experimental Methods. Edwin A. Cowen, David Hill, Dr. Christopher George, Gerhard Jirka, Marian Muste, Dave M. Admiraal, Aaron Blake, Warren Frizell, Tatsuaki Nakato, Kevin Oberg, Cliff Pugh, Chris Rehmann, Colin Rennie, Arthur R. Schmidt, Stuart Styles, Tracy Vermeyen, Tony Wahl, and David Zhu, editors, pp. 154-158. Lake Placid, New York, September 10-12.
9. 2006UT69B ("Irrigation Demand Forecasting for Management of Large Water Systems") - Articles in Refereed Scientific Journals - Torres, Alfonso F., Wynn R. Walker, and Mac McKee (2011). “Forecasting Daily Potential Evapotranspiration Using Machine Learning and Limited Climatic Data." Agricultural Water Management, 98(2011):553–562.
10. 2006UT69B ("Irrigation Demand Forecasting for Management of Large Water Systems") - Articles in Refereed Scientific Journals - Ticlavilca, Andres M. and Mac McKee (2011). “Multivariate Bayesian Regression Approach to Forecast Releases from a System of Multiple Reservoirs.” Water Resource

Management, 25:523–543. DOI 10.1007/s11269-010-9712-y.

11. 2008UT106B ("Basin-Scale Internal Waves Within the South Arm of the Great Salt Lake") - Articles in Refereed Scientific Journals - Spall, R.E. (2011). "Basin-Scale Internal Waves Within the South Arm of the Great Salt Lake," International Journal of Modeling and Simulation, 31:25-31, 2011.